QUEEN MARY UNIVERSITY OF LONDON

DOCTORAL THESIS

Meiofauna analyses of saltmarsh development with changing sea-levels in the UK

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Abstract

Coastal saltmarshes are vital ecosystems because (a) they physically buffer the land against storms and flooding from the sea and (b) ecologically they are high-productivity systems in estuaries and marine coastlines that shelter and support fish and bird populations. Saltmarshes are highly sensitive to sea level change. Any saltmarshes are now threatened by rising sea level, but how they will respond and at what rate is unclear.

Managing saltmarshes is therefore necessary, but requires a good understanding of their development in order to predict how they might respond to sea level change. Current management practice in the UK is mainly managed realignment landward and future scenarios are predicted with computer models. Both use the hypothesis of facilitation succession, whereby saltmarsh progrades seawards. An alternative hypothesis is saltmarsh development by transgression landward due to rising sea level. This thesis critically examines how saltmarshes have developed under different sea-level change regimes in order to gain an insight into how they are likely to be affected by future sea level rise.

Using established micropalaeontological techniques, Foraminifera tests and Ostracoda shells were extracted from sediment cores taken from saltmarshes representing a range of sea level change histories during the Holocene. Sampling of modern environments allowed saltmarsh vegetation zones to be characterised by foraminiferal and ostracod assemblages which were then used to reconstruct the development of saltmarshes over time as preserved in the cores. Sediment layers in the cores were dated using three techniques: Optically Stimulated Luminescence (OSL), radio carbon (^{14}C) and ^{137}Cs / ^{210}Pb.

The latter hypothesis is supported in southern England where marine transgression caused saltmarshes to migrate landwards, in contradiction to the facilitation succession hypothesis. In Scotland saltmarshes advanced seawards but due to a marine regression. Future studies should explore the applicability of these findings to saltmarshes outside the British Isles.

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Contents

Abbreviations

AIQUA Associazione Italiana per lo Studio del Quaternario

AR Arrochar study site

ASW Atlantic sea water

ATT Admiralty Tide Tables

BGS British Geological Survey

BP before present (1950 AD)

C.D. Chart Datum

CIC constant initial concentration model

CR Cree study site

CRS constant rate of supply model

CW (saltmarsh sediment) core water

DB Drumburgh study site

FSC Field Studies Council

G Gann study site

GIA glacio-isostatic adjustment

GoS Grange-over-Sands study site

GPS global positioning system

Hol Holkham study site

IR infra-red

IW Isle of Wight study site

ka thousand years (kiloannus)

KY Kyleakin study site

LA Loch Ainort study site

LARI Laboratory for Radioisotopes

LGM Last Glacial Maximum

LR Loch Riddon study site

LP living population

LPP living population percentage

LS Loch Sligachan study site

Ma million years (megaannus)

MHWNT mean high water neap tide

MHWST mean high water spring tide

MRS managed realignment site

MSL mean sea-level

NE Natural England

NERC Natural Environment Research Council

NI Nith study site

O.D. Ordanance Datum (Newlyn)

OSL optically stimulated luminescence

PM polymineral

PSA particle size analysis

QMPRF Queen Mary, University of London Postgraduate Research Fund

QMUL Queen Mary University of London

QRA Quaternary Research Association

RW Roudsea Woods study site

SBCS School of Biological and Chemical Sciences

SEM scanning electron microscope

SK Stiffkey study site

SNH Scottish Natural Heritage

SLR sea-level rise

SSSI Site of Special Scientific Interest

T Tollesbury study site

TMS The Micropalaeontological Society

TP total population

TPP total population percentage

TTI Two Tree Island study site

UK United Kingdom

UCL University College London

USA United States of America

Scale of Units used

Value	**Symbol**	**Name**
10^{-6} kg	mg	milligrams
10^{-3} kg	g	gram
10^{3} kg	Mg (t)	megagram (tonne)
10^{-6} m	µm	micrometre
10^{-3} m	mm	millimetre
10^{-2} m	cm	centimetre
10^{3} m	km	kilometre
10^{4} m^2	ha	hectare
10^{-3} l	ml	millilitre
10^{3} years	ka	thousand years
10^{6} years	Ma	million years
1 J/kg	GY	Gray
1 dps	Bq	Becquerel
10^{-3} mEq	Eq	equivalent

List of Figures

List of Tables

1. Introduction

The first chapter introduces the different types and the role of saltmarshes, explains how plant zonation is formed and summarises previous research history, including modelling and saltmarsh management. Therefore, a general introduction to relative sea-level and its changes (during the Holocene) is also necessary in order to understand the forces that influences saltmarsh development. Problems with previous models on how a saltmarsh behaves are focused on and a new hypothesis on its succession in relation to relative sea-level rise is introduced, by studying saltmarshes from the UK.

1.1. Saltmarsh definition and its ecological role

The scientific literature generally describes saltmarshes as low-lying areas of alluvial or peat deposits which are vegetated by salt-tolerant plants (halophytes). These landscapes are flooded periodically with saline water as a result of fluctuations in sea-level (tidal or non-tidal), but they are exposed to the air for the majority of time (Long & Mason, 1983; Adam, 1990; Davy, 2000). These tidal marshes are divided into coastal and freshwater tidal marshes by Adam (1990), depending on the salinity of the flooding water. However, based on the geomorphological setting, different saltmarsh types are defined. For example, Doody (2008) describes eight saltmarsh types: estuary, deltaic coastal, lagoonal, open coast (or beach plain), barrier island, loch-head, perched and beach-head. The expanded classification in Pye & French (1993) additionally includes open embayments, estuarine fringing and estuarine back-barrier saltmarshes. And in Long (1983), semi-natural and artificial saltmarshes are mentioned as well. Therefore, depending on the literature, a different number of saltmarsh types exist, but in general a "salt marsh will extend as far inland as the sea is able to dominate the ionic content of the soil solution" (Long & Mason, 1983). To avoid confusion, the macrotidal saltmarsh classification of Allen & Pye (1992) will be used in this work. It is divided into five main non-exclusive types: (1) open-coast saltmarshes that develop behind extensive intertidal flats, (2) back-barrier saltmarshes that form behind developing sand or shingle barriers, (3) estuarine-fringing saltmarshes, (4) embayment saltmarshes, and (5) loch (fjord)- head saltmarshes. In this work, different types of saltmarshes were visited as described in chapter 3.

Coastal saltmarshes can be found nearly on all continents along intertidal shorelines where their distribution is restricted to the temperate zone reaching from middle to high latitudes (Mitsch & Gosselink, 2000). In lower

latitudes, between 32°N and 38°S, the saltmarsh vegetation in the tropical zone is associated with or completely replaced by mangroves (Gupta, 1999; Woodroffe, 2002; Davis & Fitzgerald, 2004; Murray, 2006; Bird, 2008). However, this variation of vegetation with climate zones does not influence the function of these ecosystems. Coastal saltmarshes are vital because (a) they provide physical shoreline protection and (b) ecologically they are high-productivity systems. Reason (a) means that saltmarshes function as a buffer due to their "ability to dissipate the energy of incoming waves" (Davy, 2000). Therefore, they defend against storms and flooding from the sea (King & Lester, 1995). Reason (b) includes several aspects: First, saltmarshes provide shelters in estuarine and marine coastlines which support fish and bird population, e.g. feeding and nesting (Boorman, 1992; Hughes, 2004). Second, saltmarshes can function as sinks (younger saltmarshes) or nutrient sources (matured saltmarshes) (Dame & Gardner, 1993). This means that the biomass is decomposed in situ or washed out of the marsh depending on a variety of factors, e.g. successional age of the marsh, salinity or tidal range (Osgood, 2000). As example, 8000 t of plant material per year (Mitsch & Gosselink, 2000) is buried in the sediment instead of releasing it into the atmosphere as Carbon Dioxide (CO_2) (Laffoley & Grimsditch, 2009). Only rainforests in the tropics can equal the net productivity of saltmarshes (Long & Mason, 1983). One other aspect rarely mentioned is the human benefit, where saltmarshes are used as passive recreation and aesthetic (Adam et al., 2008). Also, it is utilised as grassland for domestic animals and haymaking, representing a traditional form of saltmarsh management (Long & Mason, 1983; Adam, 1990; Adam et al., 2008; Doody, 2008), see chapter 1.2.1.

1.1.1. Saltmarsh zonation and succession

In the United Kingdom (UK), an approximately total area of 45 337 ha of saltmarsh exists, with its highest distribution in England (32 500 ha) and Wales (6 747 ha) (Burd, 1989). One fifth of this area can be found along the coasts of Norfolk, Suffolk and Essex (Kadiri, 2010). There, a saltmarsh can extend over an area of 4162 ha as in the Wash, England. In contrast, Scotland with its more rocky shore, has only a few marshes (total area of 6 089 ha), with the biggest ones covering around 800 ha (Burd, 1989; Doody, 2008). However, regardless of their location, all saltmarshes are influenced by frequent inundations, the tides, resulting from the moon and sun's gravitational pulls on the seas. Throughout the world, the tide cycles show a consistency because they depend on regular astronomical events. However, the tidal range varies due to local geographical variations (Long & Mason, 1983). Therefore, positions with respect to tides (reference points) are established which are defined by the height of the low and high tide. For Britain, this point (mean sea-level, MSL) is at Newlyn in Cornwall (Dury, 1972) which is recorded as Ordnance Datum (O.D.) in tide tables. At this point, cycles of approximately 12.5 hours apart occur with two high tides. In this semi-diurnal tidal submergence pattern, every two weeks spring tide follows a neap tide which can be referred to two lines: the mean high water spring tide (MHWST) and the mean high water neap tide (MHWNT). As a result, in saltmarshes a distinctive vegetational zonation can be found

according to the different tides with reference lines reflecting elevation differences (Waisel, 1972; Chapman, 1974; Chapman, 1977; Beeftink, 1977; Sánchez et al., 1996; Olff et al., 1997; Roman, 2001; Bockelmann et al., 2002). At a saltmarsh, the MHWNT marks the boundary between the pioneer zone and the mid-low marsh zone. Above the MHWST, the high marsh zone is followed by terrestrial plants that are beyond the inundation range, see figure 1.1. An example of a typical zonation of saltmarsh plants can be found in south-east England where *Salicornia europaea* (marsh samphire), *Spartina anglica* (cordgrass), *Atriplex portulacoides* (sea purslane), *Puccinellia maritima* (saltmarsh grass) and *Elytrigia atherica* (sea couch grass) occur in this order from low to high saltmarsh (Hughes et al., 2009). In British saltmarshes, approximately 40 species of higher plants can be found, with 10 to 20 species common for individual marshes (Boorman, 2003). The upper limit of each plant zone is restricted due to interspecific competition and the lower limit due to physico-chemical factors (flooding, salinity, soil sulphides) (Olff et al., 1997; Davy, 2000). The border between the vegetated saltmarsh and the sea can be formed by a cliff which can reach from a few centimetres up to over a metre in height. Other physiographic features dissect the marsh surface, such as creeks and pools or salt pans (Long & Mason, 1983), see figure 1.1.

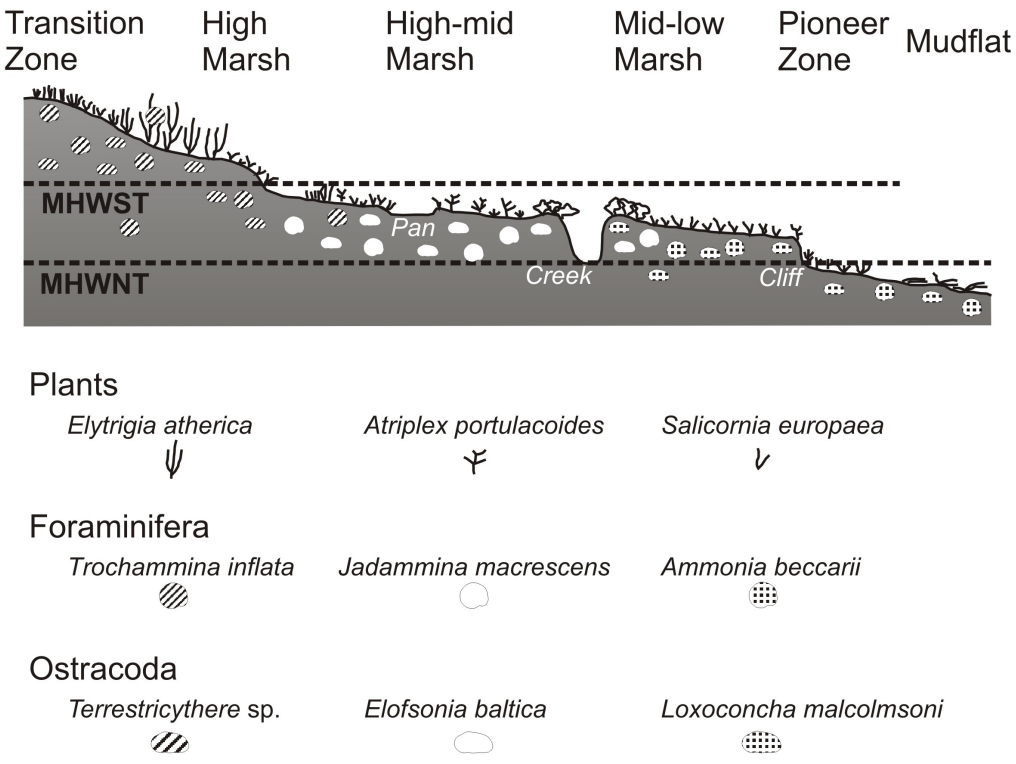


Figure 1.1.: Schematic cross section of a saltmarsh with its zonation (high, mid and low marsh) reflecting the average of the spring (MHWST) and neap tide (MHWNT) as dotted lines. One representative of plants and meiofauna (Foraminifera and Ostracoda) are given for each zone. Also, physiographic features are indicated: salt pan (pan), creek and cliff.

The natural inhabiting fauna in saltmarshes can show a similar zonation pattern to that of the plant species. This is because the environmental stress, caused by inundation (submergence, variation in water and soil salinity, waterlogging), only allows a low faunal diversity. However, those species who adapt are often restricted to their habitats (zones) (Long & Mason, 1983). Furthermore, most abundant saltmarsh animals are burrowers like the polychaete *Nereis diversicolor*. Other invertebrates such as Ostracoda are also common in saltmarshes as well as single-celled organisms like Foraminifera or Diatoms. These micro-organisms have shells and they live within (infaunal) or on (epifaunal) the sediment as a part of the meiofauna. These micro-organisms form assemblages that can be unique for each plant zone (Long & Mason, 1983; Funnell & Pearson, 1989; Brew et al., 1992; Gupta, 1999; Horne & Boomer, 2000; Boomer et al., 2003), see figure 1.1. In reality, these zonations are not strictly separated by any clear boundaries, only the distribution of the plant species on the marsh surface makes them visible. However, drainage creeks and salt pans dissect the surface intricately, leading to the development of different habitats depending on the abiotic factors (topography, temperature, salinity, oxygenation, etc.) (Adam, 1990). This can also result in a patchy distribution of plants, which can be found on a microscale level (scale of metres). Whereas, on a mesoscale level, zonation occurs (scale of tens to hundreds of metres) (Adam, 1990).

Normally however, a zonation is present on the marsh surface, because of the interspecific competition as mentioned before, leading to a linear change in vegetation. This "underlies the early ideas of [...] succession proposed by Clements (e.g. Colinvaux, 1973)" (Long & Mason, 1983). Regarding to the literature (Chapman, 1977; Long & Mason, 1983; Adam, 1990; Davy, 2000; Doody, 2008), saltmarshes are assumed to form through facilitation succession: pioneer marsh plants (*Salicornia*) settle on mudflats, stabilize the underground and facilitate sediment. The elevation increases and *Salicornia* can be out competed by mid marsh plants like *Atriplex* and *Puccinellia* until high marsh vegetation (*Elytrigia*) is reached. The result is a progradation of the whole saltmarsh towards the sea with respect to the relative sea-level (figure 1.2). Respectively, also the meiofauna within the sediment will migrate with the saltmarsh zones (Brew et al., 1992; Horton & Murray, 2007).

As an example, at Bridgwater Bay in south-west England, *Spartina anglica* has sprouted on bare tidal flats which were transformed into new low marsh. After a 20 year dominance of *S. anglica*, other saltmarsh species typical of the lower zonation invaded this area (Ranwell, 1972). Another example of seawards migration of a saltmarsh can be found on the coast of New England (north-east USA) where the accretion rates have kept pace with SLR over the last 600 years (Niering & Warren, 1980). In 1714, G.M. Lancisi first described the migration of the shore line into the sea as a result of the accumulation of alluvial sediments from the River Tiber, near Rome (Pignatti & Ubrizsy, 1989).

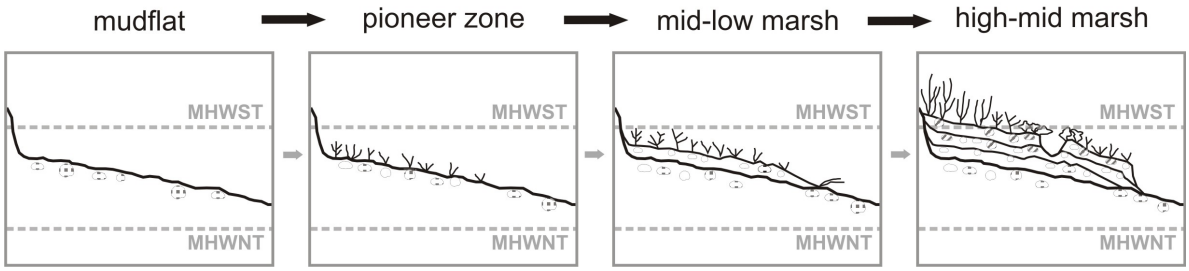


Figure 1.2.: Diagram showing a saltmarsh development through facilitation succession, reflecting the growth stages of the plant zones, starting with a mudflat to pioneer zone, over mid-low to high-mid marsh zone. The marsh develops between MHWST and MHWNT level. However, it can still expand towards the sea (progradation), forming a cliff at the front of the marsh edge, and creeks within. With each developing zone, the plant species differ, as do the meiofauna (Foraminifera and Ostracoda), as indicated by the shells in the sediment.

1.2. Threat of sea-level rise and the loss of saltmarshes

When saltmarsh plants accrete and stabilised the sediment (through facilitation succession), marsh development is influenced by different factors: sea-level changes, sediment availability and human interference (Doody, 2008). In the long term, depending on the presence or absence of one of these factors, saltmarshes grow (accretion) or reduce (erosion) in size. When accretion and erosion are in balance, a semi-stable state (equilibrium) is established (Doody, 2008). These three physical processes (accretion, erosion, equilibrium) can be found on any saltmarsh. When a saltmarsh accretes, plants invade tidal flats and the habitat can progress vertically and / or laterally. For temperate marshes, a vertical growth of 2-10 mm per year is normal (Ranwell, 1972). An example for lateral seawards migration can be found in the Wash, east England, where progression rates of 50 cm per year were measured (Doody, 2008). Young saltmarshes (recently colonized) show the highest accretion rates. In mature marshes, accretion slows down "because few tides that reach high elevations can deposit little sediment" (Davy, 2000). Here, a dynamic equilibrium occurs, with short term patterns of accretion and erosion. As a result, no overall change in the saltmarsh area occurs, merely creeks and tidal channels change position. When erosion dominates, saltmarshes transgress landwards as well as their cliffs (Doody, 2008). For example, a 2 m high marsh cliff has retreated at an average rate of 1-2 m per year since 1983 at an embayment at Higham Saltings near Gravesend, Thames Estuary (Pye, 2000). At eroding cliffs, slumping often occurs which can be colonised again by plants. However, contrary to accreting saltmarshes, vegetation die-back also takes place, as seen in a Louisiana saltmarsh (USA) due excessive submergence (Webb et al., 1995). Also, the plant zonation migrates landwards with the marsh surface, e.g. New England marsh (USA) in response to SLR (Donnelly & Bertness, 2001).

The sea-level is affected mainly by climate, and changes with the variation between warm (interglacial) and cold (glacial) periods. Since the end of the Last Glacial Maximum (LGM) between 18 000 and 20 000 years BP ago (Ray & Adams, 2001; Doody, 2008), global warming has caused ice sheets to melt. This leads to eustatic sea-

level rise due to the influx of freshwater and the thermal expansion of the water volume because of the increasing temperatures (Rayner, 1981; Woodroffe, 2002). As well as eustacy, relative sea-level shows an isostatic sea-level rise (SLR) at some localities, like in the south of Britain (Shennan et al., 2006a) which is caused primarily by tectonic or isostatic rebound and also sediment compaction (Emery & Myers, 1996). Sediment compaction means that the overlying sediment layers affect the underlying ones with their own weight which leads to the subsidence of the whole sediment deposit (Ranwell, 1972). In contrast, tectonic subsidence is defined as isostatic rebound which can be described as a compensatory upward movement of the landmasses caused by the loss of the overlying melting glaciers (Woodroffe, 2002). In the case of the UK, Scotland and north England a rising, however south England is subsiding. In Essex, sinking rates occur at up to 3 mm per year (Long & Mason, 1983), but an average of 1.5 mm per year (Shennan & Horton, 2002). Whereas, the tectonic subsidence shows its maximum in south-west England, the maximum relative land uplift (1.6 mm per year) occurs in central and western Scotland (Shennan et al., 2006a), see figure 1.3. Therefore, SLR is reconstructed on the south coast of the UK since the beginning of the Holocene, whereas in the northern part also a relative sea-level drop can be recognised. However, "recent relative sea-level rise is now outpacing estimated rates of glacio-isostatic adjustment (GIA) across the proposed Scottish uplift dome" (Teasdale et al., 2011).

Even though England subsides, sediment accretion rates with a maximum of 8 mm per year can be found in north Norfolk, east England, which exceeds the rate of mean sea-level of 1.4 mm per year (Pethick, 1981; French & Spencer, 1993). This vertical growth of saltmarshes is also recognised with average rates of 4 to 5 mm per year over the last 100 years in the Solent, southern England (Cundy & Croudace, 1996). In the Venice Lagoon, Italy, with its 3 700 ha of saltmarsh area (Silvestri et al., 2003), an extreme vertical accretion rate of 1.54 cm per year was measured. Nevertheless, the marsh edge retreats because of the eroding mudflat in front of the marsh due to the increased wave energy and tidal ranges in the lagoon. Consequently, the eroded material is accumulated on marsh land, leading to very high accretion rates. This rearrangement of sediments is evolving and causes further deepening of the Venice Lagoon (Day et al., 1998). This problem, which is caused by the increasing wave energy, can be correlated to a relative rising sea-level (Doody, 2008). This means that besides the changing sea-level, sediment availability influences saltmarsh development as well. There are four sediment sources: erosion of elevated land (sediment transport by rivers) and sea cliffs (sediment transport by tides), reworking of subtidal offshore banks and habitats within the estuary (Doody, 2008). Sedimentation rates are dictated by physical factors, but are often controlled by chemical and biological ones (Long & Mason, 1983). When there is enough sediment available, accretion occur during inundation. The marsh plants trap the suspended sediment particles in the water, which then accumulate on the marsh surface (Roman, 2001). Generally, sediment accretion in saltmarshes takes place when firstly, the tide can flood the surface and secondly, enough accommodation space is provided. The first condition for accumulation is fulfilled when the relative sea-level is rising or stagnating (Pye, 2000). The

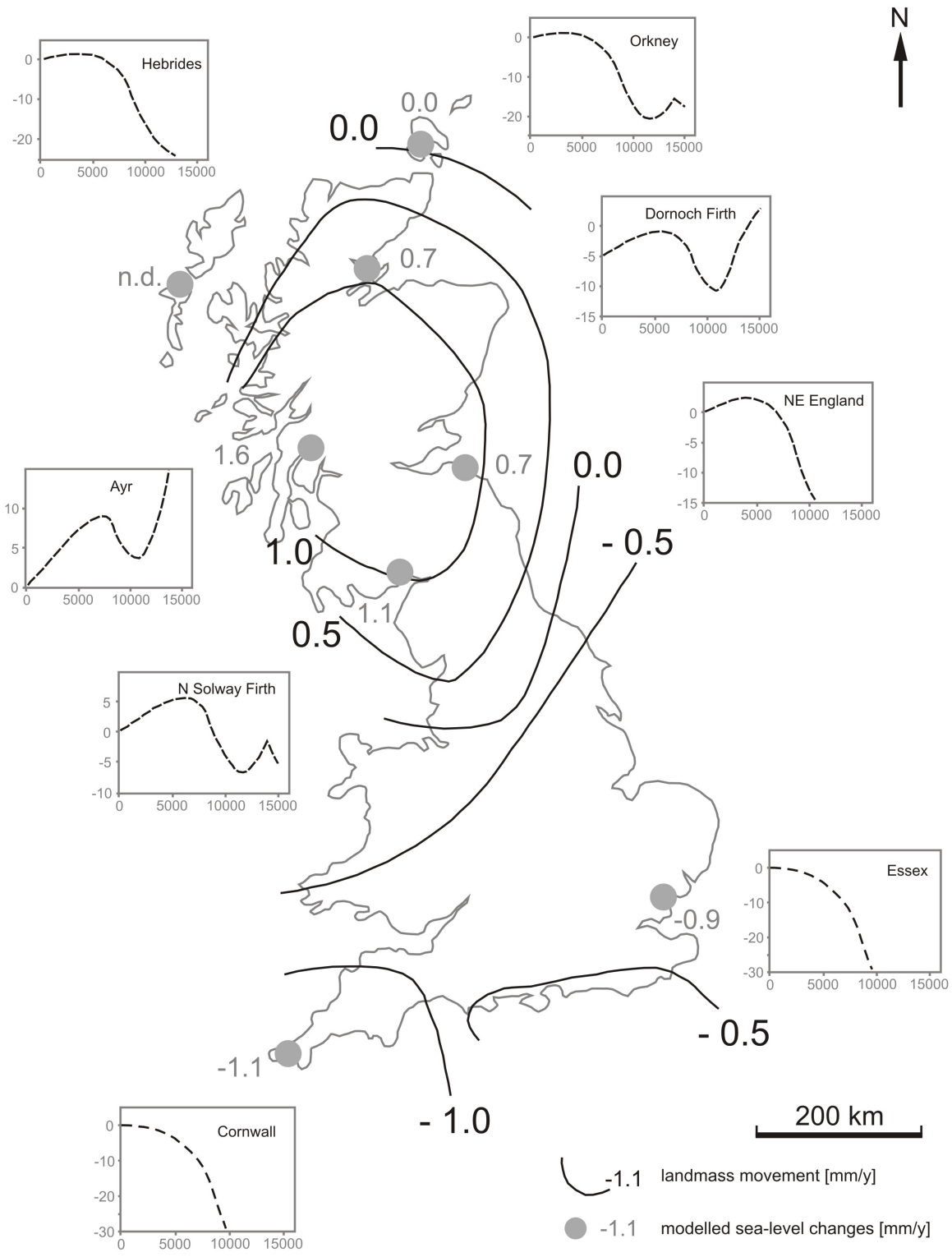


Figure 1.3.: UK with late Holocene land / relative sea-level changes [mm / year], where positive values indicate a relative land uplift (black numbers) or relative sea-level fall (grey numbers), negative values indicate a relative land subsidence or relative sea-level rise (n.d. = no data). Also, relative sea-level curves for different regions are shown, with years BP on the x-axis and metres of sea-level changes on the y-axis. The figure is modified after Shennan & Horton (2002).

saltmarsh surface can grow then vertical at a rate equal to the rate of the relative SLR (Reed, 1995; Goodman et al., 2007). The second condition is fulfilled if the accommodation space is bigger than the sum of eustasy, subsidence and compaction (Emery & Myers, 1996; Doody, 2008).

During the last century, tide gauge records show a global SLR of 1 to 2 mm per year (Pye, 2000). Globally 1-2 % each year of saltmarsh is lost, which equals an area of 140 ha (Duarte et al., 2008). In general, a coastal wetland loss of up to 90% of California (USA) (Tsihrintzis et al., 1996) and one with 40 % in France (Brittany) (Williams, 1994) was recorded. In the subsiding areas of the UK, saltmarshes especially in south-east England are showing a continuing erosion of 40 ha per year over the last 50 years. This is equivalent to two thirds of the total UK saltmarsh loss, with erosion as the driving force (Hughes & Paramor, 2004). The reason for these losses are drought, storms (hurricanes), SLR, erosion and human interference (Kadiri, 2010). For example, discharges of materials (herbicides) can accelerate the loss by decreasing the sediment stability (Mason et al., 2003). Human influences on saltmarshes probably dates back to Roman times, where wetland drainage was meant as a malaria control (Doody, 2008). Other types of saltmarsh modifications can be summarised as coastal management, which have different effects on this ecosystem, see chapter 1.2.1.

1.2.1. Wetland management and coastal squeeze

Most estuaries in Europe attained their present form between the Bronze and Iron Age (Wilkinson & Murphy, 1995). Wetland and coastal management have started here before Roman time, as mentioned above. For example, wetland drainage occurred in the Fenland Basin, east England (Doody, 2008). Besides the countermeasure of malaria, this could also have been done to prevent the extensive saltmarsh landward migration during Roman time (Pye, 2000). During medieval periods, archaeological evidence shows that sheep grazing already took place on marsh land in Essex, south-east England. Also, saltmarsh embanking started by the end of the 12th century, and in the Thames Estuary in the 13th century (Doody, 2008). These were, however, “driven by economic and social factors, not sea-level” (Pye, 2000). Radiocarbon dates the construction of the first sea walls in the 17th and 18th century, which lie all now seaward of present walls. Sea wall breaches were common features in the Crouch and Blackwater Estuary, south-east England (Wilkinson & Murphy, 1995). However, reclaiming land from the sea did not start until the 1600s, where small-scale enclosure took place, e.g. in The Wash, east England. Here, in total, an agricultural area of over 130 000 ha was claimed through drainage and enclosure. By the early 1950, a saltmarsh area of 30 000 ha was claimed alone, with further extensive enclosures between 1953 and 1983 (Doody, 2008). In Essex, a saltmarsh area of 15 000 ha has been reclaimed (Long & Mason, 1983), and an area of 40 000 ha combined in Essex, Suffolk and north Kent, south-east England (Hughes & Paramor, 2004). Compared to Europe, the USA started in the early 1700s to create land for agricultural and haymaking, e.g. in Louisiana. In

the early 1900s, this continued on to the east coast and in Louisiana, leading to the first restoration sites (Doody, 2008; Paramor & Hughes, 2005).

There are different forms of coastal management, which lead to various impacts on saltmarshes. Little to no surface modification is the result of the traditional saltmarsh management, where the tidal inundation continues: grazing, reed cutting, samphire gathering and haying. In contrast to the traditional use, stand turf cutting and sediment excavation, where the marsh would need decades to recover. Changes in the marsh topography is the result of enclosures, where the tide is excluded, such as (summer) dykes, Salinas and rise cultivating (Adam, 1990; Doody, 2008). The building of infrastructures (roads) and filling the enclosures after erecting a sea wall lead to the destruction of saltmarshes. Only enclosures that allow the marsh to remain at its original level have a change of tidal land restoration. The land behind a sea wall is prevented to accrete sediment due to the missing tide, and therefore, a lowering of the surface is the result (Doody, 2008). This means that when a storm breaches the sea wall, the hinterland is flooded. Great floods are known to occur with a 55 to 80 year intervals during the last 300 years at the North Sea coastline of the UK. An example is the event of 16th February 1736, where the Canewdon marshes were flooded, east England. Later floods often lead to sea wall breaches along the Essex coast. Reconstructing the walls proved to be a difficult task, so that it often remained breached (Wilkinson & Murphy, 1995). Or new *hard* engineering flood defences were build, like after the 1953 flood (Boorman, 2003). However, with SLR, higher sea walls are required which lead to an almost linear decrease in saltmarsh width (Garbutt et al., 2006).

Especially in south-east England, resent marsh erosions have been associated with the prevention of its landward migration. This is due to the construction of sea walls (saltmarsh enclosures or artificial barrier) in combination with a present SLR (Boorman, 2003), which shows an acceleration since the end of the 19th century (Boorman, 1992; Adam et al., 2008). The result is that the outer saltmarsh zone migrate landward, but the inner zone is unable to do the same due to the wall. The marsh then becomes squeezed between the static wall and the rising sea, resulting in saltmarsh loss. The term *coastal squeeze* describes this process (Boorman, 1992; Burd, 1992; English Nature, 1992; Cooper et al., 2001; Boorman, 2003; Garbutt et al., 2006; Doody, 2008).

As mentioned earlier, 40 ha of saltmarsh per year over the last 50 years was lost due to erosion in south-east England (Hughes & Paramor, 2004). For England and Wales, 15 % of marsh surface has been lost in 30 years, and there is a potential threat of losing further 20 %. In the USA, approximately 25 % of saltmarsh (800 000 ha) was destroyed between 1932 and 1954 (Long & Mason, 1983). SLR in combination with an increased storm frequency resulted in severer wave attacks on marshes. The construction of ever higher sea walls or concrete ones, proofed ineffective since waves were undermining them, and only lead to increasing maintenance costs (King & Lester, 1995). Therefore, the value and function of saltmarshes as natural and self-repairing flood defences in front of sea walls, was gradually realised as coast protection. Then, coastal managers were thinking of ways to create

new saltmarshes, which could be realised by either importing sediment in large-scales, or by the breaching of sea walls to let the marsh migrate landwards. The latter, where saltmarsh is re-created is called *managed realignment* or retreat (Boorman, 2003) and was introduced as a form of *soft* engineering (Garbutt et al., 2006). This method implicate the moving of sea walls further landward to release previous protected areas to the tides which would then be able to create new intertidal habitats to offset SLR (Spencer et al., 2012). Saltmarsh restoration practices, such as embanking and enclosure, were already used earlier in the USA. For example, a marsh restoration program began in 1980 by the State of Connecticut (Niering & Warren, 1980). And in 1989 the annual wetland loss in Louisiana (1 295*10^5 m^2 per year) was estimated to be worth between $77 to $544 million (Costanza et al., 1989). In the UK, the first experimental managed sites were established at Tollesbury (21 ha) and Orplands in the Blackwater Estuary, Essex in 1995 (Paramor & Hughes, 2005; Garbutt et al., 2006; Spencer et al., 2008; Hughes et al., 2009). Other managed realignment sites in south-east England are Abbotts Hall (84 ha), Wallasea Island (110 ha), Freiston (78 ha) and Brancaster (7.5 ha) (Paramor & Hughes, 2005). In total, 44 such sites are in the UK (mostly the east coat), and 94 are known to be in north-west Europe (Spencer et al., 2012), like Germany. In the Netherlands de-poldering is used as a method to restore saltmarshes (Wolters et al., 2005b).

(a) Managed realignment site (b) Tollesbury map (c) Old saltmarsh

Figure 1.4.: Photos showing Tollesbury saltmarsh with its typical vegetation and creeks by low tide (a) Managed realignment site: vegetation after 16 years, showing a plant zonation and the sea wall in the background (b) Tollesbury map: an overview of the old saltmarsh which surrounds the managed realignment site (MRS) by mid tide, north of Tollesbury in the Blackwater Estuary (image from Google Earth 2006), and (c) Old saltmarsh: forms a plateau with creek of 1 height, and a plant zonation.

However, the results of establishing managed realignment sites (MRS) to restore saltmarshes showed different outcomes. In south-east England for example, the managed realignment site at Tollesbury developed a saltmarsh after 12 years, whereas, at Abbotts Hall it showed the same progress after 5 years (Hughes et al., 2009), see figure 1.4. In the State of Connecticut (USA), along the 110 km Long Island Sound shoreline, six saltmarshes showed restoration times between 5 to 21 years. This resulted from differences in tides leading to some delays in restoration time (Niering & Warren, 1980). In other cases, marshes did not develop, but reverted to mudflats

(Pethick, 2001; Spencer et al., 2012). The Tollesbury MRS was meant to be a test case to understand the involved processes and the practical techniques behind such constructions (Garbutt et al., 2006). For example, long-term effects of inundations on soil parameters (sediment geochemical and geochemistry cycling, maturation, nutrients) are poorly understood (Spencer et al., 2008). So the question, if MRS can create new saltmarshes to counteract the process of coastal squeeze showed different answers. Furthermore, other saltmarshes did not show any signs of coastal squeeze, even though the relative sea-level is rising. For example, the embanked saltmarshes on the south Essex coast in England, showed a seaward growth between the medieval time and the mid 19th century. Also, the marshes at the open coast of the Dengie Peninsula (most wave-exposed coast) migrated 700 m seaward, even though a sea wall was constructed there 200 years ago (Pye, 2000). So, does coastal squeeze exist? So far, saltmarshes seem to keep pace with SLR and not drown. This happens in the Netherlands, where the relative rising sea-level since 1870 only led to a saltmarsh surface growth on the northern island of Schiermonnikoog. Only the sediment is merely replaced from the lower to higher elevations (Olff et al., 1997). Also, the marshes on the north Norfolk coast developed even during SLR, and this process has persisted for over 6 000 radiocarbon years (Funnell & Pearson, 1989; Davy, 2000). The already mentioned saltmarsh in the Venice Lagoon in Italy also show a vertical growth, keeping pace with relative sea-level (Day et al., 1998). Hughes & Paramor (2004) claim that only about 5% of recent saltmarsh is lost due to sea defences. The erosion that occurs in saltmarshes globally, can therefore be related to other factors. So Pye (2000) suggested that the rapid erosions in the Blackwater and Medway Estuaries in 1870 were not triggered by SLR. Other reasons for saltmarsh erosion was found in Essex, where recent studies show that the polychaete *Nereis diversicolor* is responsible for some of the regression of the marsh due to higher deposit feeding rates. This behaviour reduces the algal mats which stabilise the sediment and therefore, when the tide comes in, washes the loose sediment away (Hughes et al., 2000; Morris et al., 2004). Another invertebrate is the amphipod *Corophium volutator* which buries the seedlings of the saltmarsh plant *Saliconia europea*. This action led to decreased germination of the plant which increased the erodability of the sediment (Gerdol & Hughes, 1993). A similar situation is occurring globally after the decline of the seagrass *Zostera marina* which protects the coast against wave actions (Harmsworth & Long, 1986; Den Hartog & Phillips, 2001). Studies have shown that nitrate and phosphate inputs via fertilizer, which reaches the marsh through the run-offs from agricultural land, led to destabilized creeks. In combination with increased wave activity can also lead to erosion (Deegan et al., 2012).

1.3. Saltmarsh modelling and sea-level reconstructions

The impact of erosion and accretion due to SLR resulted in speculations as to how saltmarshes will be affected and develop in the future. For this, computer models are often used to predict long-term saltmarsh reactions, ranging

between 10 to over 100 years (Temmerman et al., 2004). The models often focus on geomorphological processes rather than biotic ones (Kirwan et al., 2016). Meaning, that the focus is on sediment processes like accretion, transportation, suspension, compaction and so on (Pethick, 1981; Allen, 1990a; Day et al., 1999; Mason & Garg, 2001; Williams, 2003; Temmerman et al., 2004). In general, there are two types of numerical models, one that is used by academics (dynamic process-based model), and one that policymakers and managers use (large-scale landscape model). However, accretion normally increases non-linearly, and dynamic feedbacks through which the ecosystem can adapt vertically, are not considered by both models. This leads to an overestimation of wetland vulnerability to SLR which was shown with a meta-analysis by Kirwan et al. (2016). Here, less than 5% from 140 study sites (Spain, France, UK, USA and Canada) are submerging, suggesting the survival of most saltmarshes. This is possible due to saltmarsh migration, which depends on the angle of upland slopes (Niering & Warren, 1980; Pethick, 2001). A gentle slope leads to marsh expansion (migration is greater than erosion), whereas, a steep slope leads to marsh reduction (erosion is greater than migration). Through this, there is a potential to offset up to 78% of saltmarsh losses by transgressing marshes, "even if all existing marshes were to drown or erode in place" (Kirwan et al., 2016). However, transgression rates of saltmarshes have hardly been measured. The vertical accretion otherwise has, and results of dynamic models suggest that marshes are able to keep pace with a SLR of 10 to 50 mm per year (Kirwan et al., 2016). This would fit with the current mean SLR of 1.4 mm per year. And where, for example, saltmarshes with an 8 to 10 mm per year vertical accretion rate in the Blackwater Estuary exceed SLR (Pethick, 2001). Even if models can predict accretion rates, feedbacks between this and other aspects of climate change are not yet included. Also, a better understanding of the lateral processes of saltmarshes is needed, in respect to anthropogenic and climatic factors, and how they influence marsh migration (Kirwan et al., 2016).

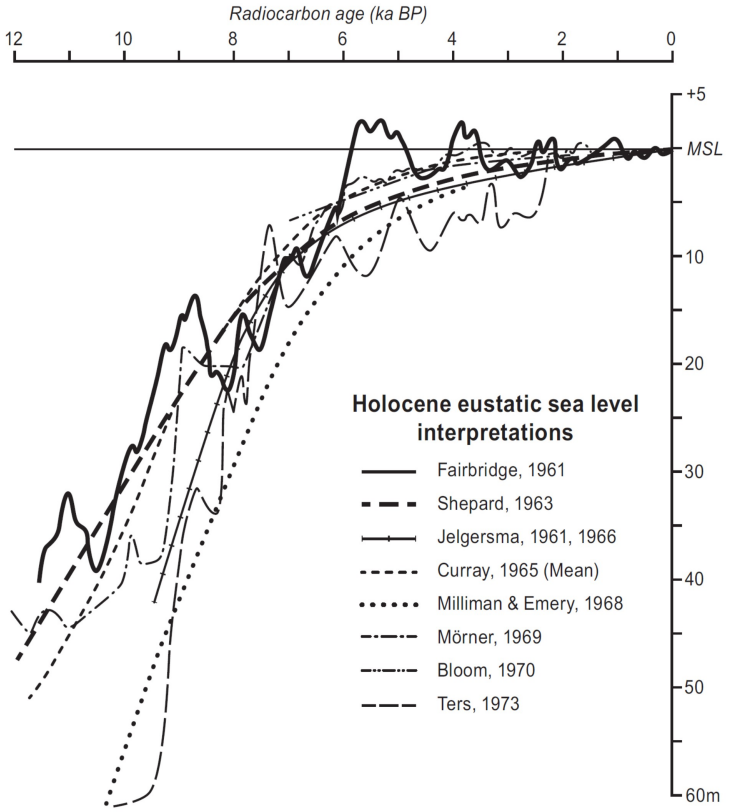
Besides that models are not able to include all feedback mechanisms yet, two other problems should be mentioned here. The first one addresses the collection of data. To acquire the parameters to feed a model, preparations are necessary such as on site measurements or observations (field study), laboratory experiments and remote sensing (Pethick, 1981; Niering & Warren, 1980; Allen, 1990a; Day et al., 1999; Mason & Garg, 2001; Williams, 2003; Temmerman et al., 2004; Kirwan et al., 2016). For the latter, historical maps, satellite images or aerial photographs are used, to extract data about plant communities (Zhang et al., 1997; Sadro et al., 2007) or spatial distribution of different habitats (Mason et al., 2010). The limit of this method is the short time-scale of historical maps and recent technology like satellites, whereas, most modern saltmarshes formed over 4 000 years ago (Kirwan et al., 2016). Laboratory experiments as well as field studies, or observations, are also limited in time and scale. Due to time management, one to ten year studies are common (Day et al., 1999; Mason & Garg, 2001; Deegan et al., 2012). So, there is a "need for long-term field studies that integrate and quantify physical and biological processes and the related feedbacks at different spatial and temporal scales" (Wolters et al., 2005a). As

for the scale, most studies use small plots, normally of 1 m^2 size (Pennings, 2012), with an exception by Deegan et al. (2012) who experimented on a saltmarsh area of 30 000 m^2.

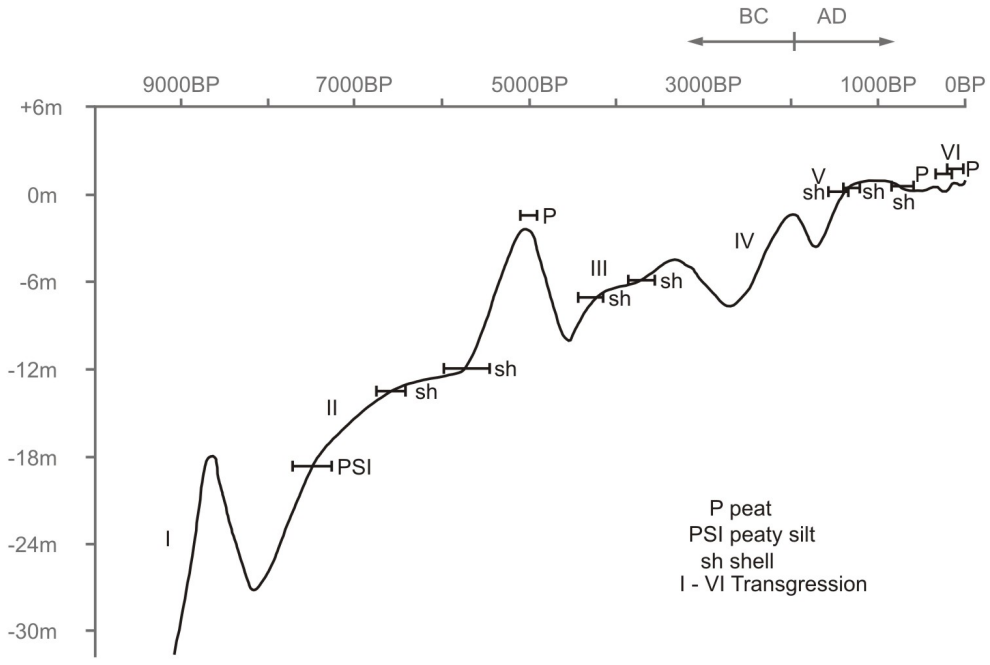
The second problem involves invasive species like the cordgrass *Spartina* spp., which is often ignored as such in models or used in experiments (Deegan et al., 2012; Kirwan & Mudd, 2012). Native species are found on the east coast of America as well as outliers occur on the west coast of North America, Europe and Tristan da Cunha (Doody, 2008). The problem are hybrids (e.g. *Spartina anglica*) and invasive species (e.g. *Spartina alterniflora*), which replace native species leading to a decrease in biodiversity, interrupt natural ecological functions and change faunal habitats (Harvey & Associates, 2013). Besides these alterations, the expansion time of the invaders differs and therefore, is often not predictable. For example, slow spreading was observed from *S. alterniflora* in Willapa Bay in Washington state (over 50 years) and *S. anglica* in California (over 30 years). Whereas, *S. densiflora* occupied three sites in Central Bay in California within 30 years. It was observed that the plant distribution was often coupled with warm years. In contrast, die back also occurred on a large-scale, due to the inhabitation of previously unoccupied niches, leading to its own destruction. The key factor for this seemed to be watter-logging (Doody, 2008). Although, non native species were also deliberately planted to colonise mudflats and stabilise sediment in MRS (Paramor & Hughes, 2007). The negative environmental effects outweighs the positive economic use (Doody, 2008), and therefore, it has to be controlled (Harvey & Associates, 2013). One exception is *S. anglica*, where it is now accepted as an endemic *native* in the UK (Doody, 2008).

1.3.1. Holocene sea-level changes

As future saltmarsh development is predicted with the help of models, so are past sea-level changes reconstructed with geophysical models. Although, other methods (like indicators) are used as well, the results show different sea-level curves with one trend, a rising sea-level for the Holocene (figure 1.5). This trend continues since the LGM, where the sea-level was between 130 to 120 m below present (Pye, 2000; Doody, 2008; Murray-Wallace & Woodroffe, 2014). Model-generated paleo-sea-levels produce very smooth curves, like that of Shepard (1963) (figure 1.5 a). It is unclear, if any aberrant points describe sea-level oscillations or are just noise. Restrictions to reconstruct past sea-levels are presented "by the age-resolving power of radiocarbon dating, vertical confidence limits of proxy sea-level indicators, and the statistical validity of curve-fitting to empirical observations of relative sea-level data" (Murray-Wallace & Woodroffe, 2014). However, since the ends of the LGM, the sea-level records show the highest resolution. Besides U-series and radiocarbon dating, indicators (proxy) were used for reconstructing past levels. These proxies, of biological, geomorphological or geological nature, are features that appear within a limited elevation range, like saltmarshes or mangroves. These ecosystems exist within the intertidal zone, and using particular organisms can narrow down the reconstruction range of former sea-levels (Murray-Wallace & Woodroffe, 2014). This is possible by determining the elevation of certain indicators (e.g. faunal assemblages)



(a) Global sea-level curves



(b) Thames Estuary mean sea-level curve

Figure 1.5.: Holocene sea-level trends, showing a SLR (a) Global sea-level curves: copied from Murray-Wallace & Woodroffe (2014) showing different interpretations of sea-level reconstructions, and (b) Thames Estuary mean sea-level curve: from south-east England, based on radiocarbon dates, faunal, lithological and geotechnical data, indicating six transgression stages (I to VI), after Greensmith & Tucker (1973).

with respect to their age (geochronological or radiocarbon) and tidal datum (Horton & Edwards, 2006a; Shennan et al., 2006a). For example, saltmarshes exist within a particular tidal range, so that any accumulated sediment beneath it can contain evidence (proxies) of past sea-level changes. A large range of proxies have already been used to reconstruct sea-levels, e.g. isolation basins (Selby et al., 2000; Romundset et al., 2015), pollen (Long, 1992; Massey et al., 2008), testate amoebae (Gehrels et al., 2001; Charman et al., 2010), Diatoms (Zong & Horton, 1999; Plater et al., 2000; Horton et al., 2006; Kemp et al., 2009), Ostracoda (Boomer, 1998; Frenzel & Boomer, 2005; Cronin et al., 2010; Scott et al., 2011) and Foraminifera (Scott & Medioli, 1978; Horton, 1997; Gehrels, 2000; Edwards & Horton, 2000; Haslett et al., 2001; Gehrels & Newman, 2004; Horton & Murray, 2006; Horton & Cluver, 2008; Callard et al., 2011; Mills, 2011; Kemp et al., 2012; Barlow et al., 2014). The chapters 1.3.2 and 1.3.3 give a general overview on Foraminifera and Ostracoda since they were used in this study, see chapter 1.4.1. Each proxy has its own confidence limit and also has to be evaluated critical since alterations could have obscured its correlation to sea-levels, e.g. transportation, bioturbation, erosion, weathering (Murray-Wallace & Woodroffe, 2014). For example, sea-level reconstructions with agglutinated tests of Foraminifera have a precision of ± 5 cm (Scott & Medioli, 1978; Reinhardt et al., 1996; Horton & Murray, 2006). Therefore, most studies rely on the use of multiple indicators to determine Holocene sea-level positions, like a combination of peat, shells and stable isotopes (Caesium, Lead, radiocarbon) (Greensmith & Tucker, 1973; Devoy, 1982; Heyworth & Kidson, 1982; Wilkinson & Murphy, 1986; Cundy & Croudace, 1996; Nikitina et al., 2000; Gehrels et al., 2006; Kemp et al., 2010; Teasdale et al., 2011).

Even though modelled sea-level curves are smooth, in reality, the sea-level oscillates, showing transgressions and regressions (Devoy, 1982). This can be reconstructed with multiproxy methods, like dating peat and shells and other faunal, lithological and geotechnical data (Wilkinson & Murphy, 1986; Horton & Edwards, 2005). For example, in 34 m of sediments, the reconstruction of the regional sea-level from the Thames Estuary show six transgression phases (I to VI). The overall trend, however, indicates a relative sea-level rise through the Holocene (figure 1.5 b). Here, the dates of the transgressions I and IV are only conjectured, whereas, the phases II, III, V and VI can be dated to 7 500, 4 000, 1 400 and 300 years BP (Greensmith & Tucker, 1973). Similar Holocene marine sequences, described as Thames I to V, were identified by Devoy (1982) with the help of 94 dated pollen data, and peat from south-east England. Even though five sequences were described, six transgression phases were recognised. Wilkinson & Murphy (1986) described six Holocene stages (I to VI) for the same area. Here, additional archaeological data divided the Holocene into six cultural stages (I to VI) as well. New data, reconstructed from the southern North Sea by Behre (2007) show a total of ten transgressions, see figure 1.6. Although, all data reveal a trend of sea-level rise for the Holocene, oscillation phases show regional differences. This can be based on relative sea-level changes and differences in sediment depositions along the coast. For example, the oldest transgression phase can only be found in sediment deposits from Foulness Island and Dengie

Greensmith & Tucker (1973)		Devoy (1982)		Behre (2007)		
phase	years BP	stage	years BP	stage	years BP	time period
R	250, 173, 118	Thames V	1750 to 0	Dunkirk IV transgression	250	Modern times
T VI	1100			Regression 7 Dunkirk IIIb transgression	500 850	High & Late Middle Ages
T V	1434 +/- 110 to 1265 +/- 100			Regression 6 Dunkirk IIIa transgression	1100 1250	Early Middle Ages
R	120 AD	Thames IV	2600 to n.d.	Regression 5 Dunkirk II transgression	1600 1950	Roman Iron age & migration
T IV	?			Regression 4 Dunkirk Ib transgression	2100 2300	pre Roman Iron age
R	3350 to 2400	Thames III	3850 to 2800	Regression 3 Dunkirk Ia transgression	2650 2850	Bronze Age
T III	3936 +/- 100, 3580 +/- 75			Regression 2 Calais IV transgression	3250 3900	
R	4959 +/- 65 to 4260	Thames II	6575 to 5410	Regression 1 Calais III transgression	4400 5300, 5100	Neolithic Age
T II	7516 to 5650					
R	8700 to 7750	Thames I	8200 to 6970	Calais I & II transgression	7800, 6400	
T I	?					

Figure 1.6.: Oscillating sea-level data (phase / stage) with ages (years in BP) and human culture periods (time period) from Greensmith & Tucker (1973) with six transgressions, Devoy (1982) for the Thames Estuary with five stages and Behre (2007) from the southern North Sea (German coast) with seven regressions. R = regression, T = transgression, n.d. = no data.

Flats areas in Essex, south-east England (Greensmith & Tucker, 1973). Whereas, the same deposits only appear in cores offshore of Germany (Behre, 2007). Other local variations in relative sea-level changes are linked with isostatic rebound like in Scotland. Here, during the same time period as in south-east England, a relative sea-level fall also occurred after an increase (Shennan et al., 2006b). A detailed overview of different relative sea-level trends during the Holocene for Great Britain can be found in Shennan & Horton (2002).

1.3.2. Foraminifera

Foraminifera are an order among the Phylum Protista and are "Cytoplasmic body enclosed in a shell of one or more interconnected chambers" (Loeblich & Tappan, 1987; Murray, 2006). This means, they are unicellular organisms (protists), related to Amoeba, capable of altering their shapes with the help of pseudopodia. These are part of the protoplasm and contained within the shell called a *test*. From here, the protoplasm can extend beyond it in form of a streaming net (reticulum), containing granules, which emerge from an opening (aperture) of the test. They are used for feeding, protection, attachment, movement, respiration, disposing of waste products and constructing the test (Haslett, 2000).

Foraminiferal tests are made of different materials which is used primarily to divide the order Foraminifera further into suborders. At present, a total of 16 suborders are recognised (Gupta, 1999). The history of its classification and its taxonomic problems are further discussed in chapter 5.1. Most analysed Foraminifera in this thesis belong to the suborders: Texulariina, Rotaliina and Miliolina as well as Allogromiina. The first one contains Foraminifera with a test made out of sediment particles that are agglutinated together with a mix of organic and calcitic cement. The other two suborders summarise the Foraminifera with calcium carbonate tests. The difference between them is the orientation in which the calcite crystals grow, leading to a hyaline (see-through, Rotaliina) or porcelain white surface (Miliolina). Bedsides these hard-shelled forms, also soft-shelled ones exist, like the suborder Allogromiina. Here the test wall is mainly organic (proteinaceous) and very fragile (Larkin & Gooday, 2004). There are of course other wall materials like silica as summarised under the suborder Silicoloculinida or naked forms without any test and therefore with no fossil record (Pawlowski et al., 1998). These listed suborders summarises all different known wall materials. For dividing the suborders further, features like aperture(s) position, ornamentation, chamber arrangement and shape are used (Brasier, 1970) as well as environmental adaptation (benthonic vs. planktonic) (Gupta, 1999). However, the emphasis is placed on features visible with an optical microscope which makes Foraminifera morphospecies (Murray, 2006).

Foraminifera can be found in marine and brackish environments, no freshwater represents are known. They appear from the intertidal zone down to the deep see (abyssal plains). Among the estimated 10 000 species, only 40 to 50 are planktonic forms, the majority comprises of benthonic species (Gupta, 1999). These can live either as epibenthos (on the sediment, epifaunal) or endobenthos (within the sediment, infaunal) or attached to plants

(Bignot, 1985), but are still able to move between. The biological focus is on the sexual and asexual reproduction of Foraminifera leading to a distinct morphological dimorphism. Since the 20th century Foraminifera are also used for marine environmental reconstructions. Here, they can be used as proxies for reconstructing water depth, sea-levels, temperature, oxygen content, salinity, pH, productivity, age dating (index species) and so on. This is only possible due to their preservation in sediments as fossils. The first benthonic forms are known from the Cambrian age (541 to 485.4 Ma), whereas planktonic ones appeared later during the Jurassic age (201.3 to 145 Ma) (Gupta, 1999).

1.3.3. Ostracoda

Ostracods belong as a subclass among the Class Maxillopoda within the Phylum Arthropoda according to some authors (Newman, 1983; Haslett, 2000), but others see the Ostracoda as a Class in its own right (Brasier, 1970; Bowman & Abele, 1982; Horne et al., 2002; Cabral & Loureiro, 2013; Brandão et al., 2015) as is followed here. Further, the Class Ostracoda is subdivided into two subclasses: Myodocopa and Podocopa (Horne et al., 2002; Cabral & Loureiro, 2013; Brandão et al., 2015). An overview of their classification history and taxonomic problems are further discussed in chapter 5.2. Ostracoda are aquatic Crustacea (typically 0.3 - 1.5 mm long) that consist of a calcitic shell (unsegmented carapace) which is formed of two valves, left and right (Horne & Boomer, 2000). The bivalved carapace is enclosing the soft body with its appendages and is linked over a dorsal hinge and an elastic ligament. So, "the body hangs inside the carapace like a sac. It is attached in the dorsal region and is fixed laterally to the valves by muscles" (Bignot, 1985) which leave scars on the inside of each valve (adductor muscle-scar pattern) (Horne & Boomer, 2000). The adductor muscles are used for closing, whereas, the hinge opens the carapace. If the valves are opened, the appendages (generally 5-8 pairs) can protrude and be used for locomotion, feeding, reproduction, as sense organs and for cleaning the internal cavity (Bignot, 1985; Horne & Boomer, 2000).

To classify living Ostracoda, the morphology of their appendages is used. Whereas, for fossilised Ostracoda only the characteristic features of the carapaces, respectively their valves, are used to classify them: valve (carapace) contour, features of the ventral edge, characteristics of the marginal zone, hinge structure, ornamentation and pores (Bignot, 1985). Due to their calcite carapace, Ostracoda possess a long fossil record from Ordovician age (485.4 to 443.8 Ma) to Recent (Haslett, 2000). Among arthropods, Ostracoda have the best fossil records (Horne et al., 2002). Over time, Ostracoda have shown the following trends: reduction in size and number of muscle scars, growing complexity of the hinge, modification of the contour with the dorsal edge, progressive calcification of the internal lamella, extension and increased complexity of the marginal pores, appearance of normal cribrate pores (Bignot, 1985).

The living habitats of Ostracoda range from freshwater over brackish to marine (Horne et al., 2002). The genus *Terrestricythere* as a semi-terrestrial Ostracoda, has also adapted to survive for short periods on 'emerging' intertidal land (Horne et al., 2004). Regarding the 'Cologne Database of Ostracoda' more than 65 000 living and fossil species with subspecies are known. Approximately 120 shallow brackish-water and marine species are known from Britain. And fewer than 10 are commonly associated with saltmarshes, showing normally a low diversity, but high abundance. They all belong to the Podocopida, Superfamily Cytheroidea. Their distribution is primarily controlled by substrate type, temperature, salinity and oxygen availability (Horne & Boomer, 2000). Ostracoda are Metazoa and therefore, possess a central nervous and digestive system, complex genital organs and a median eye within the carapace (tubercule). Dimorphism is common due to divided sexes, where males tend to be less numerous than females (Bignot, 1985). Saltmarsh Ostracoda reproduce eggs and have life cycles of one to three generations per year. The growth periods are during spring, summer and autumn, with temperature as the major controlling factor (Horne & Boomer, 2000). Young Ostracoda grow in discontinuous stages (instars) via eight successive moultings, until the adult stage is reached (Bignot, 1985). Since all instars are often well preserved in sediments (as fossils), Ostracoda are widely used for different palaeoecological reconstructions as proxies, same as Foraminifera (Horne & Boomer, 2000).

1.4. Aims and objectives of this study

As described in chapter 1.2, sediment availability, human interference and sea-level changes are the primary factors influencing saltmarsh development (Doody, 2008). However, so far there has been evidence to suggest that sediment is mostly being sufficiently available, also during periods of sea-level rise (SLR). For example, this can be shown for the last 4 000 years, since saltmarshes have been formed (Niering & Warren, 1980; Wilkinson & Murphy, 1995) during a time of global SLR. Given that SLR rates have tripled due to global warming since the beginning of the 19th century (Pye, 2000), it can be assumed that enough sediment was available, because accretion rates of high marshes are similar to historical rates of global SLR. Furthermore, only less than 5% of saltmarshes are not keeping up with increased rates of SLR worldwide (Kirwan et al., 2016). Therefore, sediment was mostly available in sufficient quantities so that saltmarshes were able to accrete sediment and grow vertically with SLR, e.g. North Norfolk saltmarshes (Pethick, 1981; Funnell & Pearson, 1989; French & Spencer, 1993; Boomer, 1998; Davy, 2000; Boomer & Horton, 2006; Kirwan et al., 2016). Human influences however, have a vast majority of different impacts on saltmarshes. For example, sea defences (Adam, 1990; Boorman, 2003), run-offs (fertilizer, herbicides,...) (Niering & Warren, 1980; Kadiri, 2010), invasive species (Harvey & Associates, 2013) and other forms of management (e.g. grazing) (Doody, 2008) that do not affect all saltmarshes in the same way (Pennings, 2012). Also, not all marshes are influenced by humans. And when looking back on how old

most saltmarshes are, humans had different influence on their development, except in a few extreme cases, like the Venice Lagoon and the Mississippi River Delta. Here, human influences are accountable for decreasing the sediment supply and / or increased subsidence rates which is responsible for saltmarsh loss (Kirwan et al., 2016). Consequently, this study focuses on the influence of sea-level changes on saltmarsh development (in the UK), also because marshes are perceived to be under the threat from a rising sea which causes saltmarsh loss (Pye, 2000). Therefore, understanding how they are affected by this process (SLR) is imperative.

Studies on saltmarsh development and its migration with SLR were described by Redfield (1965) from New England, USA. Here, the marshes were formed during relative SLR between 3 000 to 4 000 years ago, dated with peat deposits underneath the marsh. Then, keeping pace with relative SLR, the saltmarshes showed a migration towards the sea (progradation) as well as the hinterland (transgression) (Redfield, 1965; Niering & Warren, 1980), see figure 1.7. A similar saltmarsh development was observed in Delaware (Elliott, 1972) and Connecticut (Niering et al., 1977). Here, a transgressive and progradational marsh migration is possible, because the sedimentation rate is similar or greater than relative SLR, and combined with a (postglacial) land submergence, leading to a marsh vertical growth in equilibrium with the relative sea-level (Redfield, 1965).

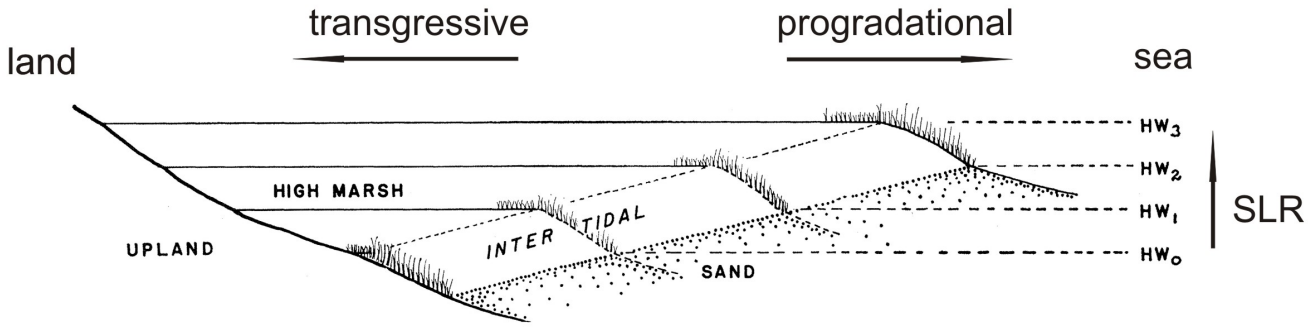


Figure 1.7.: Saltmarsh development of a New England (USA) marsh with continued sedimentation and SLR. The marsh surface shows a migration of the ecosystem towards the hinterland (transgression) as well as the sea (progradation). HW_0 to HW_3 describe stages of a relative rising sea-level (SLR). Image modified after Redfield (1965).

Progradation of a saltmarsh is normally known during periods of relative sea-level fall (Pye, 2000), see figure 1.8. However, this can also be the case when SLR takes place but the land is subsiding due to tectonic subsidence (isostatic adjustment) during postglacial periods (Redfield, 1965). An example are the saltmarshes in New Hampshire (Keene, 1971). Here, rapid rates of submergence started around 6 850 years BP (dating peat deposits underneath the marsh) and only slowed down at 4 000 years BP, but still continues. This submergence allowed sedimentation to build up the estuarine floor, which saltmarsh plants could then colonize.

Transgressive saltmarshes were described by Allen (1990) as a landward *roll-over* in the Severn Estuary, where the marsh migrated toward the hinterland in response to relative SLR (Allen, 1990b; Pethick, 2001), see figure 1.9.

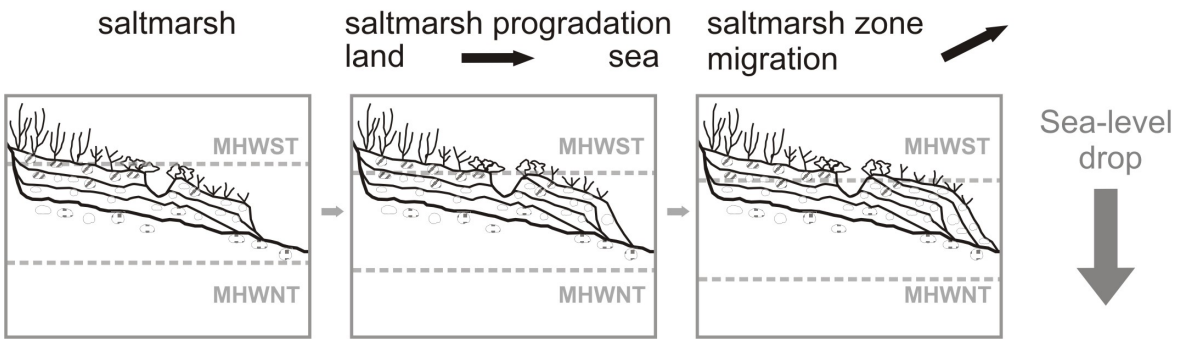


Figure 1.8.: Saltmarsh develops through facilitation succession in response to a relative sea-level drop. The whole marsh migrates towards the sea (progradation). Furthermore, the plant zones as well as the meiofauna (Foraminifera and Ostracoda) are shown, reflecting a progradating saltmarsh.

This saltmarsh transgression combines a landward migration with a vertical upward growth in equilibrium with relative SLR, in order to maintain its place in the tidal frame. Other examples are known from the New England marshes (USA), where the plant zonation is migrating with the marsh surface landwards in response to relative SLR (Donnelly & Bertness, 2001). Also, saltmarshes on the north Norfolk coast show this transgressive migration pattern. One characteristic of a transgressing marsh is that these events have been found on subsiding coasts (Keene, 1971; Pye, 2000).

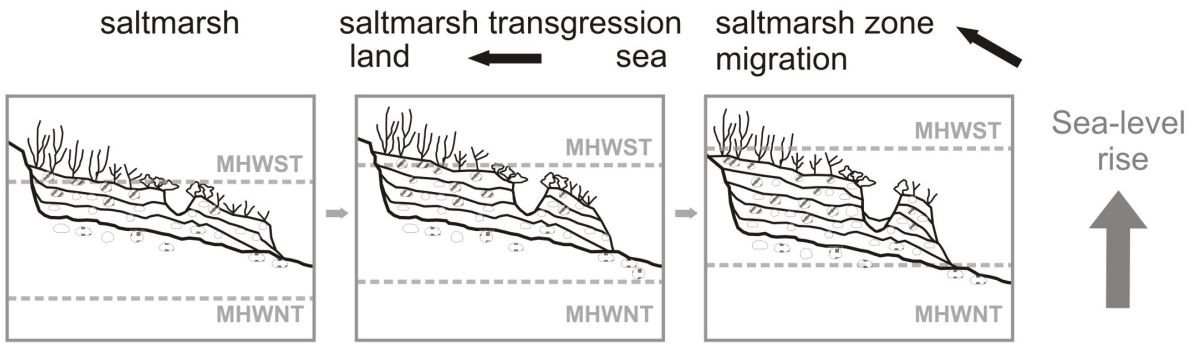
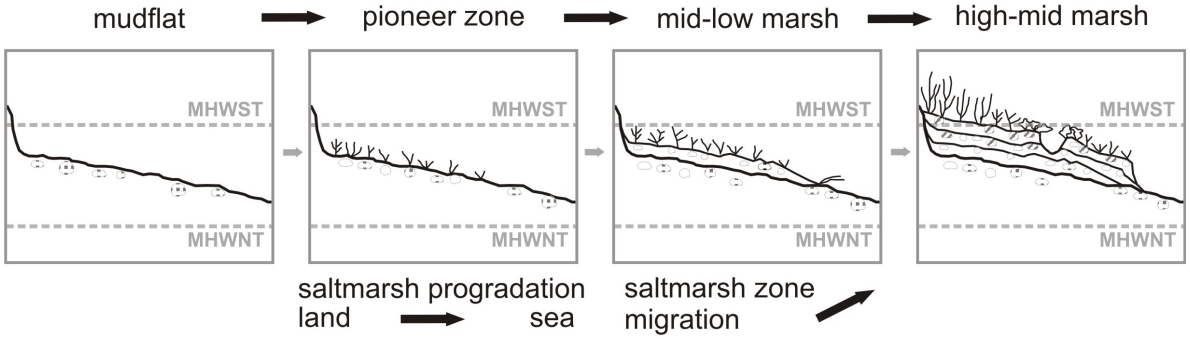


Figure 1.9.: Saltmarsh developing with relative sea-level rise by migrating towards the hinterland (transgression). Here, the cliff in front of the marsh is eroding, whereas, the marsh surface keeps pace with SLR. Also, the plant zones as well as the meiofauna (Foraminifera and Ostracoda) are shown, reflecting a transgressive saltmarsh.

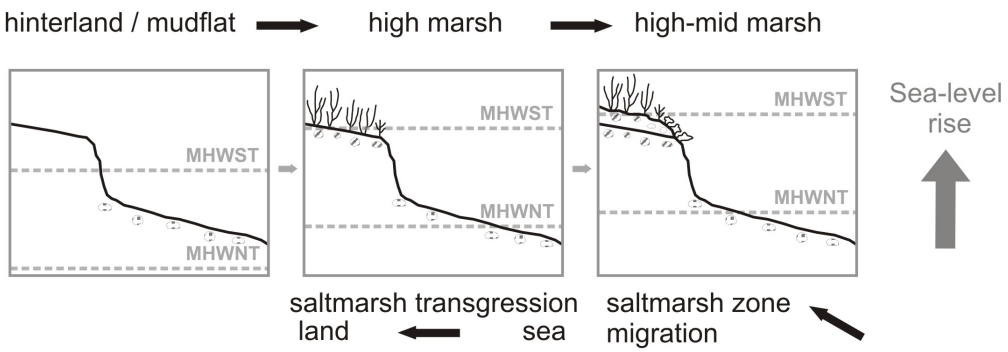
These different migration patterns from saltmarshes were observed in response to relative sea-level changes, also see chapter 1.2. However, when the relative sea-level rise, the cliffs in front of a marsh erode (Doody, 2008; Pye, 2000) and even vegetation die back occurs (Webb et al., 1995). So, when a saltmarsh is known to form through facilitation succession, starting with a pioneer zone, how would it form by SLR? What are the relative roles of SLR, transgression, facilitation and progradation in saltmarsh development and succession?

1.4.1. Hypothesis testing

Due to the observations on saltmarsh migration as described above, two hypotheses are going to be tested on how marshes developed in respect to relative sea-level changes during the Holocene. According to the literature (Chapman, 1977; Long & Mason, 1983; Adam, 1990; Davy et al., 1999; Davy, 2000), saltmarshes are assumed to form through facilitation succession (Hypothesis 1): pioneer marsh plants (*Salicornia*) settle on a mudflat, stabilize the substrate and facilitate sediment accumulation. The elevation increases and *Salicornia* can be outcompeted by mid marsh plants *Atriplex* and *Puccinellia*, until high marsh vegetation (*Elytrigia*) is reached, see chapter 1.1.1. The result is a progradation of the whole saltmarsh towards the sea, see figure 1.10 (Facilitation Model). In this PhD project, an alternative hypothesis proposed by Dr Rob Hughes was tested (Hypothesis 2), representing the opposite of the facilitation model (from low to high marsh). Here, the saltmarsh develops from the highest to the lowest marsh (instead of lowest to highest) and is migrating towards the hinterland, see figure 1.10 (Sea-level Rise Model). For this type of saltmarsh development, two conditions must be fulfilled: First, the angle



(a) Facilitation Model (Hypothesis 1)



(b) Sea Level Rise Model (Hypothesis 2)

Figure 1.10.: Diagrams showing two saltmarsh developments with its typical vegetation and meiofauna (a) Hypothesis 1: saltmarsh develops a pioneer zone on the mudflat which grows from a mid-low to a high-mid marsh (b) Hypothesis 2: saltmarsh starts with developing high marsh on the hinterland because the slope of the mudflat is too steep for plant growth during a fast relative SLR.

of the slope of the mudflat is too steep in order for pioneer plants to start growing (Niering & Warren, 1980;

Pethick, 2001). Second, a very fast relative sea-level rise takes place in order for the plant growth to begin with the high marsh stage on the hinterland rather than on the mudflat, e.g. after the Last Glacial Maximum (LGM). Then, with the SLR the marsh migrates landwards (transgression), where each time the tide is flooding the marsh surface, sea water with the suspended sediment reaches further onto the hinterland, due to its rising level, and accumulates there.

To test both hypotheses, first, a study area had to be selected were relative sea-level changes influenced saltmarsh development. Such a place is Great Britain, where the land mass of the northern area rises (with relative sea-level rise and fall) and the southern area subsides (with relative sea-level rise) due to isostatic rebound, see chapter 1.2. For example, on the Essex coast in south-east England, a relative sea-level rise can be reconstructed for the last 10 000 years, whereas relative sea-level changes recognised from the Isle of Skye, include a relative sea-level fall (figure 1.3). The main area of interest is along the coast of south-east England and along the western coast up to Scotland, see chapter 3, where in total 14 saltmarshes were chosen for this research.

Secondly, a methodology on how to reconstruct saltmarsh development had to be found. For this, a similar approach as in sea-level studies was used, as mentioned before. Marsh plants do not preserve well in the sediment, so, saltmarsh meiofauna can be used as proxies, especially Foraminifera and Ostracoda (chapter 1.3.2 and 1.3.3). In contrast to plants, both micro-organisms with their hard carbonate shells are well known for their resistance against erosion and can be found well preserved in the sediment (Brasier, 1970; Bignot, 1985; Haslett, 2000). The shells themselves can reflect the ecological conditions like temperature or salinity due to the species preference to a certain living area with its conditions (Buzas, 1968; Gupta, 1999; Boomer et al., 2003; Ito et al., 2003). In saltmarsh sediments these preserved micro-fossils are also used for local sea-level reconstructions, see chapter 1.3.1 (Scott & Medioli, 1980; Horton, 1999; Horton & Edwards, 2005). A disadvantage of this method is that Foraminiferal assemblages can vary due to factors other than elevation alone (Scott & Medioli, 1980). In this case, to combine the received information of Foraminifera and Ostracoda shells will lead to better results and a broader overview about the past ecosystem than the use of only one micro-organism. Furthermore, for the UK, Foraminifera in saltmarshes show a stronger correlation to elevation than salinity, as shown for USA marshes (Horton, 1999; Horton & Edwards, 2005; Horton & Edwards, 2006b). Therefore, the species of these micro-organisms, as they show a vertical zonation just like the saltmarsh plants on the surface (Murray, 1979; Funnell & Pearson, 1989; Brew et al., 1992; Gupta, 1999; Horne & Boomer, 2000; Horton & Murray, 2007; Viehberg et al., 2008; Loureiro et al., 2009), and can be used to reconstruct marsh development with their assemblages from sediment cores, see chapter 2 about methods. By analysing the succession of these assemblages, which represent different marsh zones (high, mid, low marsh) within the sediment cores, the marsh development can be determined because of its migration in respect to relative sea-levels, see figure 1.11. When the saltmarsh core shows a succession from high over mid to low marsh from top to bottom, then the marsh developed through facil-

itation succession (Hypothesis 1, core 1). However, if the opposite marsh sediment sequence is found, with low to mid over high marsh, from top to bottom of the core, then the saltmarsh developed with SLR (Hypothesis 2, core 2). Or, if the sediment is extracted from the high marsh area, the marsh succession can show high marsh throughout the core (Hypothesis 2, core 3). Also, besides the micro-fossils, particle size analysis (PSA) will help to understand the sedimentation history of the marsh by analysing the sediment cores.

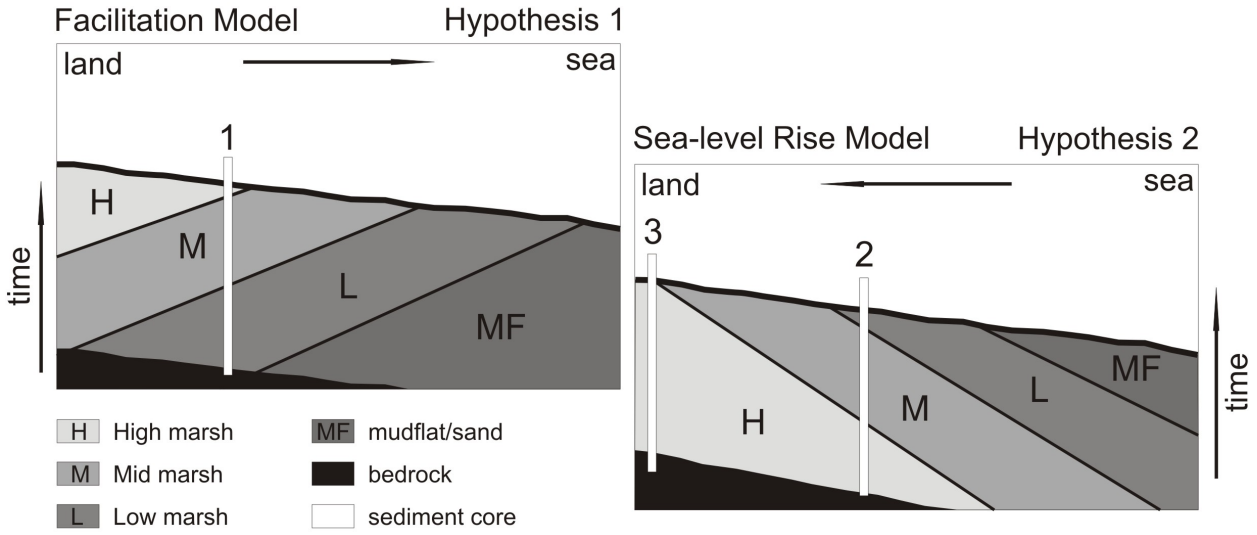


Figure 1.11.: Hypothesis 1 = Facilitation Model with seaward migration of the saltmarsh. A sediment core (1) drilled through the marsh reaches from low over mid to high marsh from bottom to top. Hypothesis 2 = Sea-level Rise Model where the marsh zonation is shifting towards the hinterland. A sediment core (2) drilled through the marsh reaches from high over mid to low marsh from bottom to top, or if taken from the high marsh surface, the sediment core (3) shows only high marsh throughout.

One problem in saltmarshes is that not every area is influenced equally by the sea and other ecological factors. For example: Whereas in some places the creeks are eroding, they can be refilled somewhere else. Or in one sheltered area the marsh could be migrating seawards, whereas the other side of the marsh could be developing landwards (Allen, 2000). In order to avoid this problem, in each saltmarsh several surface samples for the laterally and several sediment cores for the vertically and laterally investigation were collected (Boomer et al., 2003; Culver et al., 2006; Horton & Edwards, 2006b; Viehberg et al., 2008). Given that the Facilitation Model reflects a saltmarsh by retreating relative sea-level, it is predicted that the succession of core 1 should be found in the northern area of Great Britain, due the relative sea-level changes including a sea-level drop there. Furthermore, the Sea-level Rise Model with its succession of core 2 and 3 should be found in the southern area of Great Britain due to the relative sea-level rise there, see figure 1.12.

When the succession of the saltmarsh zones within the sediment cores were analysed, it was also imperative to know the age of the marsh. This could then be used to correlate the saltmarsh development with its relative sea-level history. Due to high costs regarding age dating methods, at least for one specific marsh (Tollesbury),

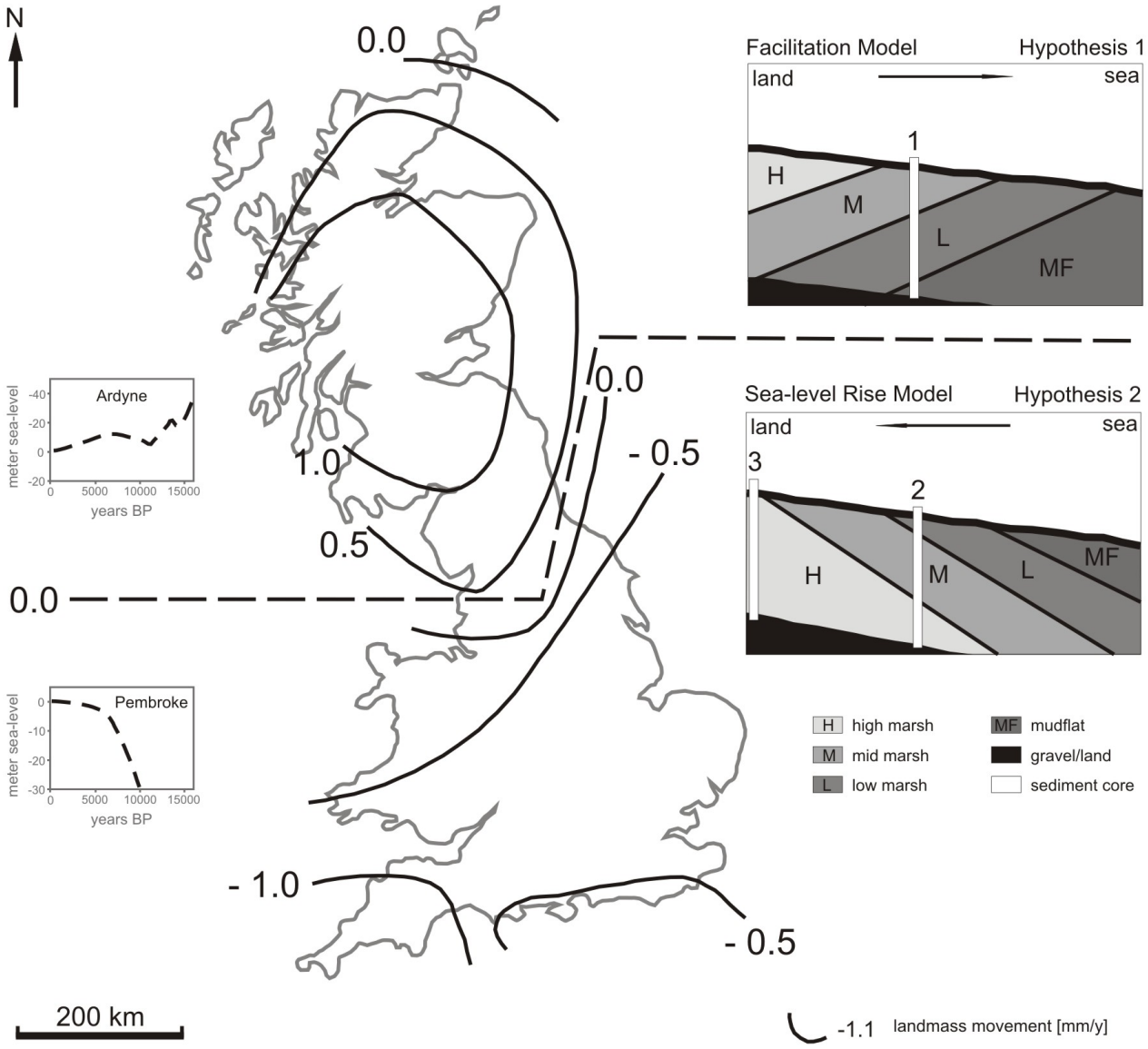


Figure 1.12.: UK with late Holocene land / sea-level changes [mm / year], positive values indicate relative land uplift, negative values indicate relative land subsidence (modified after Shennan & Horton, 2002). In northern UK with a relative sea-level fall for 7 000 years, the expected marsh developed from low to high (Hypothesis 1). In the south, a relative sea-level rise since 10 000 years probably led to a marsh development from high to low (Hypothesis 2). The dashed line indicates the boundary between the subsiding and rising land.

four different dating methods were used, see chapter 7. For other locations, the age of a saltmarsh was extracted from literature if it was available. With the known age, a better understanding on how relative sea-level changes influenced saltmarsh development in the UK was possible.

One other problem was addressed and tested in chapter 8, the resilience of carbonate shells. Even though Foraminifera and Ostracoda shells are known to be well preserved in saltmarsh sediments (Brasier, 1970; Bignot, 1985; Haslett, 2000), this had to be tested, due to the acidic marsh sediment. Therefore, a dissolution experiment was carried out with Foraminifera tests (calcareous and agglutinated) over six months. Here, extracted saltmarsh sediment water was used and the dissolved carbonate was measured as total alkalinity, as well as pH. The results of this experiment are expected to give a better insight on how well carbonate shells are preserved in saltmarsh sediments. Also, this would answer whether or not calcareous Foraminifera were present, if none would have been found in the sediment cores.

2. Methods

The following chapter summarises the methods used in this study, explaining the sampling strategy behind the collected sediment surface samples (including a seasonal study) as well as the coring. In the field, the saltmarsh zones as well as each sample location, including their elevation, were measured with a GPS. The analysis of the samples in the laboratory then included sieving, picking and sorting of Foraminifera and Ostracoda species. For the sieving a new method had to be devised and tested due to sediment clumping. Further, scanning electron microscope images were made of the micro-organisms. Also, a particle size analysis was carried out on the remaining sediment of the analysed core samples to test, if any grain size changes correlate with meiofauna assemblages.

2.1. Sediment sampling strategy

One way to reconstruct saltmarsh development in response to relative sea-level changes is by analysing the sediment (cores) which is trapped by saltmarsh plants with each tidal cycle. Then, either the sediment itself, the remnants of plants (leaves, roots, stems, pollen) or the meiofauna (invertebrates, algae, protozoan) can be used as proxies in the sedimentary record to describe the succession of a marsh.

The sediment, if laminated, can give an idea about how fast the saltmarsh develops (by dating it) (Teasdale et al., 2011). Or by analysing the grain size with particle size analysis (PSA, chapter 2.5), if the sediment is not layered (bioturbation), can indicate any changes of environmental conditions. Therefore, it is tested if particle size changes occur in saltmarsh sediment cores, where a coarser sediment would represent low marsh and finer particles indicate high marsh due to the effects of sediment transportation on the particle size distribution on a marsh surface (Nolte et al., 2012). Then, particle size changes within the core could be compared with changes in the meiofauna succession to identify possible correlations, e.g. finer sediment occurs together with high marsh meiofauna. This correlation could then help to identify marsh zones within the sediment core in the case when the meiofauna is absent, e.g. due to dissolution of the shells (Haslett, 2000). However, beside a time frame, the sediment might not reflect saltmarsh zones changes with a relative sea-level on a more detailed level.

Plants instead could be helpful due to their zonation which depends on the elevation that changes with a rising or falling relative sea-level. The problem here is that the plant remains preserve only partly, or not at all in the

sediment, or pollen are washed away with the tides, or roots have spread over several metres depth. This renders a reconstruction of the marsh in more detail very difficult. Another option is to use the meiofauna that fossilise well due to agglutinated shells. In this case, Ostracoda (invertebrates) and Foraminifera (protozoan) both fulfil the criteria and form assemblages specific to the saltmarsh zones which change together with the plants that shift with the elevation due to changing relative sea-level (Edwards & Horton, 2000; Gehrels, 2000; Haslett et al., 2001; Horton & Murray, 2007; Polovodova et al., 2009). Also, the living micro-organisms can be found in the top 2 cm which then preserve within the sediment, meaning that a resolution on the centimetre scale is possible for identifying the history of a saltmarsh. In order to do so, vertical distributions of recent assemblages with fossilised ones have been compared in this study.

First, the Foraminifera and Ostracoda were collected with sediment surface samples at 2 cm depth. From each saltmarsh site, surface samples included high, mid and low marsh as well as creeks or mudflats, sometimes salt pans (chapter 2.1.1). Precautionary measures against fluctuations in the diversity of the meiofauna due to their life cycle, was prevented by sampling in different marsh zones (low, mid and upper) over a period of 14 months in the Tollesbury saltmarsh in Essex (chapter 2.1.2). Second, the fossilised Foraminifera and Ostracoda were sampled from sediment cores ranging from one to five metres depth, depending on the sediment. These were extracted preferably in the high to mid marsh. As a result, with surface and core sampling, the vertical and lateral growth and change of a saltmarsh was covered.

2.1.1. Surface sampling

The surface sampling was guided by Horton & Edwards (2006b) work on saltmarsh Foraminifera and Ostracoda. However, the main focus is on the former taxon based on over a century of research on benthonic Foraminiferal distribution (Laidler, 2002). In contrast, more literature about freshwater and marine than brackish Ostracoda is published and information is sparse on the latter group (Frenzel, 2009). Therefore, the sampling strategy had to consider the sampling location within a marsh (distribution) and sediment depth (assemblage) including taphonomic processes based on Foraminifera information (Murray, 1991), but Ostracoda were not left out if data existed (Horne & Robinson, 1982).

For the surface sampling locations in the field, it was assumed that the distribution of Foraminifera species was related to the elevation (Funnell & Pearson, 1989; Brew et al., 1992; Gupta, 1999; Horne & Boomer, 2000; Horton & Edwards, 2006b) and not to salinity as found in American saltmarshes (de Rijk & Troelstra, 1997). This is related with the lack or not enough input of freshwater at the UK sites (Swallow, 2000). Hence, the different marsh zones indicated by plant species and the sediment including plants was collected. Overall, samples were extracted from each plant zone including mudflats, creek (rim and bottom) as well as salt pans. At grazed marshes, samples from grazed and ungrazed sites were collected regarding their elevations. The problem of small scale

distribution variations within the marsh zones of microfossil species was avoided by sub-sampling from each zone which was combined to one sample per zone. These, often three sub-samples, were taken randomly within a range of at least 1 m^2. The patchiness of species over small lateral distances is controlled by temperature, oxygen content, pH and salinity as well as different food sources (Bradshaw, 1968; Hohenegger et al., 1989).

The Foraminiferal assemblage includes different species with varying abundance per zone consisting of living and dead specimens, forming the total assemblage. Whereas the life assemblage represents a snapshot of a specific time, the composition of the dead assemblage consists of "a. production and mortality of the living assemblage [and] b. postmortem changes [...]" (Murray, 1982). High variations of living assemblages were observed from various saltmarshes (Buzas, 1968; Scott & Medioli, 1980; Morvan et al., 2006; Horton & Murray, 2007) ranging from "small lateral distances as well as the high seasonal variability of foraminiferal abundances" (Swallow, 2000). Ostracoda are no exception in this regard either (Horne & Robinson, 1982; Ruiz et al., 1997; Cabral & Loureiro, 2013). These variations for Foraminifera occur due to micro-environmental changes (Scott & Medioli, 1980), vegetation, creeks, microtopography (Van der Molen, 1997) and clumping effect of reproductive blooms (Buzas, 1968; Swallow, 2000). For Ostracoda these changes depend on sediment type (Ruiz et al., 1997), "temperature, pH, and the life-cycles and migratory habits of individual species" (Horne & Robinson, 1982). In the case of the dead assemblage, patchy distribution occur as well as shown at a middle marsh in North Carolina, USA (Kemp et al., 2011). In contrast, including other studies (Buzas, 1968), the high and low marsh assemblages showed no variations. However, for the mid zone greater variability occurred due to changes of environmental factors e.g. porewater salinity, organic and clay content (Horton & Cluver, 2008). Furthermore, higher elevation differences of middle marshes influence variability and tidal distortion (Kemp et al., 2011).

In conclusion, the total assemblage consisting of life and death assemblages, show different variations within marsh zones depending on abiotic and biotic factors as mentioned above. Additionally, taphonomic processes lead to post-depositional changes like selective preservation (dissolution) and transport (destruction) (Rijk, 1995). The former one takes place due to the acidic pH within the marsh sediment (below pH 7) where calcite shells of microfossils partly or totally dissolve (Green et al., 1993). The pH shows "a good correlation with oxygen values both during the diurnal and tidal cycles" (Phleger, 1970). Only the agglutinated Foraminifera, whose shell consists of sediment particles can preserve (Haslett, 2000), but eventually are destroyed by bacterial or chemical decay (Murray, 2006). Also, transportation occurs daily due to tidal cycles, storms and runoff from rivers, but also ice, wind, predation and floating plants move empty shells (Murray, 1991). Here, it is important to distinguish between specimens that lived *in situ* (autochthonous) and those who were transported (allochthonous). Detecting the difference is possible, because while in motion the shells collide with particles and therefore are successively destroyed. This destruction, as for dissolution, starts with the biggest chamber, leaving broken and abraded tests as well as thin-walled and size-sorted assemblages behind (Haslett, 2000; Murray & Alve, 2000). However,

"small-scale post mortem transport leads to the homogenization of the assemblage" (Morvan et al., 2006). Besides lateral, also vertically movements of specimens occur due to infaunal species and bioturbation which can change the total foraminiferal composition (Rijk, 1995). Normally, Foraminifera live epifaunally in the top 1 to 3 cm of the sediment above the *anoxic black mud* (Murray, 1982). However, infaunal species have been found alive in different saltmarshes at depths ranging from 8 down to 50 cm (Horton & Edwards, 2006b). These species, including bioturbation of burrowing animals, leads to a redistribution of Foraminifera where specimens are found in deeper sediment layers (Gupta, 1999). The results of downward and upward moving particles (Murray, 1991) is limited by food sources or oxygen level (Gupta, 1999). Below 1 m depth the historical layer starts "where material is beyond the influence of short-term postmortem processes, thus being effectively fossilised, and the main processes are diagenetic" (Murray, 2006).

Consequently, the ongoing question is what assemblage should be used concerning palaeoecological reconstruction: "live (biocoenosis), dead (thantocoenosis) or total (live plus dead) assemblages" (Horton & Edwards, 2006b). For the latter one stands the reason that "the total population integrates the small seasonal and spatial variations into a definable assemblage that reliably reflects prevailing marine conditions" (Scott & Medioli, 1980). Standing against this argument: "In human terms, it is like taking a census of both the living population and the dead in the graveyards. We would not consider such figures to be meaningful [...]" (Murray, 1982). Kemp (2011) suggests the use of dead assemblages only, but ecological studies have to focus on the living population (Murray, 1982; Murray & Alve, 2000). So, after locating the sampling spots based on the plant zones and being aware of assemblage variability, it was decided to use the total assemblage, except for the seasonal study. This was based on the assumption that to compare the sediment core with surface samples, the total population in both cases have to be compared and correlated against each other. Also, each saltmarsh zone showed a clear assemblage that could be distinguished from each other by using the raw data. If possible replicates of surface samples were done for the marsh zones. However, a similar distribution pattern of calcareous and agglutinated species was observed repetitively at nearly all study sites. Further, with mostly agglutinated Foraminifera species dominating the higher marsh surface, the usage of stain (Rose Bengal) to separate the life and dead assemblage provided some problems, e.g. living specimens were not completely stained (chapter 2.1.2). Therefore, it was decided against using the stain on surface samples, except the ones for the seasonal study. Finally, addressing the question of sampling depth, only the top 2 cm of the surface were collected. Even if studies of other UK marshes showed that over 90% of Foraminifera were found to be in the top centimetre, epifaunal as well as infaunal species (Horton, 1997; Horton, 1999; Murray & Alve, 2000; Horton & Edwards, 2006b), one more centimetre was added to include possible fluctuations.

After each sediment sampling, the tools (hand shovel and knife) were cleaned and the samples placed in labelled plastic bags. At the University they were stored in a 10°C cold room until further analysis.

2.1.2. Seasonal study

The reason to conduct a seasonal study was that not much is known about living saltmarsh Ostracoda and Foraminifera and because for the microfossil assemblages (from different marsh zones) to be used for reconstructing saltmarsh development, the impact of seasonal variability had to be known, especially if major fluctuations occur during their life cycle throughout the year (Murray, 1982).

The only seasonal study was carried out at the main site in Tollesbury, on a small randomly chosen peninsula of the inner saltmarsh. This location was selected because of the close proximity and easy access throughout the year. Each a sample was collected from high and mid marsh (including algae) and the bare creek edges (low marsh) bimonthly, beginning in February 2012 until April 2013. Taking samples every month would have been too time consuming, but a three-month period could lead to a "significantly under-estimate or over-estimate the boundary between foraminiferal zones by as much as 0.94 m" (Horton & Edwards, 2006b). Furthermore, not only monthly but also annual changes in population patterns would be possible. Monthly, peaks of living populations occur during summer with a trough in winter (Scott & Medioli, 1980), where calcareous forms dominate in summer (Horton & Edwards, 2006b; Horton & Murray, 2007). Moreover, "paralic foraminifera do not have reproducible annual life cycles" as shown at a French saltmarsh (Morvan et al., 2006). Even Horton & Murray (2007) mentioned a possible population differences between years. Therefore, instead of 12, 14 month were sampled to see if this would also be the case at Tollesbury saltmarsh.

In preliminary tests on surface samples, Foraminifera were found in all marsh zones, but Ostracoda only appeared below high marsh. This, as well as containing "a sufficient number of specimens to allow an assessment of species proportions and diversity indices with the required accuracy" (Schönfeld, 2012) was taken into consideration when deciding the sample size. Therefore, the collected sediment amount per zone varied due to abundance differences of Ostracoda and sediment composition variations which influenced Foraminifera abundance in marsh zones. Normally, the total specimen number to a unit volume or sample weight (10 cm^3 or 1 g of dry sediment) is the standard procedure (Scott & Medioli, 1980; Schönfeld, 2012). From high marsh 50 cm^3, mid marsh 30 cm^3 and creek 10 cm^3 of sediment was sampled with 10 cm^3 tubes reaching 2 cm deep. Further, the dark green algae growing on the *Atriplex portulacoides* was collected as well. Then, the bagged samples were submerged within a solution (1 g per litre) of Rose Bengal ($C_{20}H_4Cl_4I_4O_5$) for at least 24 hours. This allowed to stain living organic particles (proteins) pink. Living Foraminifera and Ostracoda were stained pink, whereas the dead specimens remained white (Murray & Alve, 2000; Murray, 2003; Gehrels & Newman, 2004).

However, problems with this staining method are known: First, the stain could only be used to distinguish living Foraminifera, not Ostracoda. This is due to the organic layer Ostracoda possess that is stained always pink, even if the shell is empty. Second, Foraminifera tests could be stained completely pink due to bacteria and other

organisms that would use the tests as a home (Murray, 1991). Third, even if Foraminifera were alive, some of them were not stained at all. Especially in high marsh, where organic particles agglutinate together with sediment and tests, the stain was not taken up. Probably because some species' cytoplasm can fail to take up the stain (Laidler, 2002). Or, the "pre-fixed protoplasm was too stiff and the internal foramens of the tests were often too narrow or plugged and thus did not facilitate a complete impregnation of the test infill" (Schönfeld, 2012). Fourth, death, reproduction and growth stages can lead to empty shells, but protoplasm could still remain or the organic lining would be stained. Fifth, especially agglutinated forms made it difficult to see the stain due to their tests' opaque nature (Bernhard, 2000).

In conclusion, these problems had to be considered when identifying living Foraminifera. Therefore, some practice was necessary to understand that different species would stain differently when alive. For example, the green protoplasm of *Elphidium* was bright green in the last three chambers, but the rest of the test was pink. Only if the whole test was stained or completely white was it deemed dead. In the case of Ostracoda, it was simple to estimate the living specimens because they still had all their appendages and organs intact, which could be seen through their carapaces.

2.1.3. Sediment core sampling

The core sampling was done with a gouge auger of 1 m length, which was half open on one side, for removing the collected sediment inside the metal-case of 3 cm diameter with a small trowel. The core equipment included several 1 m long extensions with screw top and a handle. The corer was inserted vertically in the soil by pushing it in until 1 m depth was reached with following rotational movements to ensure the loosening of the sediment before lifting it out of the ground. If water was present, this process had to be done slowly or the sediment remained in the created hole due to water pressure. The removed corer plus sediment were laid out on the ground. With a scale, 10 cm sections of the sediment were measured and put in a labelled plastic bag. Then the corer was cleaned of remaining mud, preventing contamination and the process was repeated until it was not physically possible to move the corer further into the ground. All core samples were then stored in a 10°C cold room. This procedure was the same for all cores, except at two sites: Gann and Holkham.

The three Gann cores had already been sampled by Rob Hughes and were cut into 20 cm sections for processing in the laboratory (chapter 2.2). They were also the first completely analysed sediment cores that could be used to test how large the samples should be in order to find a suitable number of specimens (300) for different sediment types (Gann contained sandy silt). It was decided that 10 cm is a suitable length because a longer core sample would be too imprecise for any marsh zonation reconstructions, and a shorter sample might contain not enough micro-organisms if the sediment was too sandy.

The Holkham core NNC 17 had already been sampled when it was cored in 1997 (Boomer & Horton, 2006). A re-sampling was suggested by Ian Boomer and done at the BGS, where it was stored. There, a 9 m long sediment core, stored in 1 m sections, was cut in half where one side was used for sampling only. It showed various holes per metre, indicating a repeated sampling over the years. One problem was the dried out sediment that was slightly loose when sandy and completely hardened when muddy. Therefore, a handsaw had to be used to cut out the samples which were only 2 cm long and 3 cm thick. Of each metre, three samples (top, middle and bottom) were extracted and stored in a labelled bag. In the laboratory, the only difference to the preparation as described in chapter 2.2 was that each sample was filled in tubes with water and soaked for one week to soften the sediment for the following sieving process.

2.2. Sample preparation and analysis

All sediment samples were wet sieved in a tub with water through a 1 mm and 125 µm sieve. Any material smaller than 125 µm was lost. The residue of each sieve was washed into metal containers. For the 125 µm fraction the new extraction method was used, as described in chapter 2.3. After each sieving process the sieves were thoroughly cleaned by hand and brushed under water. Furthermore, the 125 µm sieve was immersed in 5% Methylene Blue ($C_{16}H_{18}N_3SCl$) solution for 1 minute to dye the remaining particles in the sieve. These could then be identified as foreign material if they should appear in the samples, preventing contamination (Bignot, 1985). After the sieving process, the metal containers with their different sample residue was placed in an oven at 60°C for at least 72 hours. Here, specific agglutinated Foraminifera with thin walls were at risk of compaction which lead to chamber collapsing (Rijk, 1995), but it could not be prevented. When the samples were completely dry, they were weighed and stored in labelled glass bottles (Haslett, 2000).

Afterwards, the dried sediment was poured on a small dish with a raster and black bottom where the micro-organisms were picked out into a micropalaeontological slide (Cushman, 1959; Bignot, 1985; Brasier, 1970; Haslett, 2000) under a binocular lens type Nikon SMZ1000 stereo-microscope. From each sample it was tried to pick out between 250 to 300 specimens of Foraminifera as well as Ostracoda (Patterson & Fishbein, 1989; Murray, 1991; Schönfeld, 2012). Even if a number of 500 specimens would be more accurate, the time trade-off would be larger. Also, the error margin for the 95% confidence interval for 300 specimens would be only ± 2, and for 200 specimens ± 4 (Laidler, 2002) which should be efficient enough.

Then, the picked specimens were identified (chapter 5) and glued onto a micropalaeontological slide with a grid to count and distinguish the different species at one glance (Murray, 1979).

2.3. Meiofauna analysis - extraction experiment

While sieving the surface samples as described in chapter 2.1.1, a problem occurred during the drying process. Due to the high amount of plant remains and other organic particles in these samples, the sediment grains including the micro-organisms agglutinated together. Therefore, it was nearly impossible to pick out the Foraminifera or Ostracoda shells without breaking them. Using water to dissolve the fused lumps was a possibility, but it would have taken too long to extract enough specimens per sample without damaging them in the process.

In the literature, several methods for the mechanical extraction of microfossils are described (Cushman, 1959; Brasier, 1970; Murray, 1979; Bignot, 1985; Haslett, 2000; Schönfeld, 2012). One attempt to separate the shells from the remaining sample is done by using *floating*, where the sieved and dried sample is put in cold water so that the air filled tests are floating on the water surface (Cushman, 1959). This was done with a very sand rich surface sample (from Loch Riddon), but two problems were encountered: first, the organic material was also very light and floating together with the shells on the surface and second, sediment filled shells remained on the ground.

Therefore, another method related to spinning and decanting was tried (Cushman, 1959; Brasier, 1970). The residue of the 125 µm sieved sample that still remained in the metal container with water was gently agitated by hand so that the lightest material in the sample was suspended and the heavy particles remained on the bottom. When the sediment was on the bottom of the container, it was tipped to one side, allowing the water together with the floating material to be decanted into a second container. Only half of the floating material was removed, then water was added and the process repeated until the water was clear of any suspended particles. The last stage included decanting the remaining water from the sediment where heavier black organic particles were also removed into the second container which was now filled with water and the organic content. Both of the containers were put in the oven and dried at 60°C until the samples were dry. Subsequently, the first container (125 µm I) had an agglutinated mat of organic materials, whereas, the second one (125 µm II) contained loose sediment. Then, both samples were picked to see were the microfossils were most abundant.

At first glance, this method seemed to work, with almost all shells still remaining with the sediment sub-sample (II), but to be sure an experiment had to be conducted. For this, the *Atriplex*, the algae growing on *Atriplex* and the creek rim surface samples from the seasonal study from Tollesbury were used for the experiment because of their high organic content. Further, the monthly sampling and analysing of the samples allowed a comparison of the picked shells, including seasonal variability (changing abundances). Another criterion was that the samples were searched through for Ostracoda only, because of the high amount of Foraminifera the experiment would have taken too long otherwise. Also, a similar method has already been described by Cushman (1959) as *spinning* for Foraminifera only, where the technique is similar to gold panning. Finally, Ostracoda shells are lighter than Foraminifera tests since they are not often filled with heavy sediment, their walls are not made out of several

calcite layers or sediment particles and often single valves were encountered. In total, 60 samples were analysed during the experiment, for the results and discussion see chapter 4.

2.4. Illustration of specimens

After identifying and separating the Foraminifera and Ostracoda species, it was important to use a scanning electron microscope (SEM) (Bignot, 1985) for publication. Before the scan, the specimens had to be coated with gold under high vacuum for 105 seconds for better electronic conduction. The SEM at UCL was a Jeol JSM-6480LV high-performance, Variable Pressure Analytical Scanning Electron Microscope and was used with the help of Jim Davy. The settings were: 7 kV, high vacuum, 100 to 190 µm resolution, WD 12 mm, Spotsize 29. Of each analysed study site, the most abundant Foraminifera were used for SEM imaging as well as rare Ostracoda (chapter 5). Further, three chemical analyses of minerals were conducted (chapter 6).

2.5. Particle size analysis

Besides the micro-organism analysis for reconstructing saltmarsh development, a particle size analysis (PSA) was also performed. Due to time constraints, PSA was only performed on: the Holkham NNC 17 core, the 2.5, 4 and 5 m Tollesbury cores, the 3.9 m Two Tree Island core, two of the 1 m Gann cores, and all Loch Riddon cores (chapter 6).

Each sediment core sample has a length of 10 cm (chapter 2.1.3), but sediment was only extracted from the middle 2 cm for PSA (preferably wet), because the sediment often showed no significant layering and so random samples were picked. Then, only 2 g of each 2 cm sample was used for analysis, and replicates were done of each 5th sample. The pre-treatment started with putting the samples in a beaker with 20 ml of hydrogen peroxide (H_2O_2) to remove all organic particles and heating it on a hot plate to 30°C, to speed up the process. The same amount of H_2O_2 was added (up to three times) until the sample showed no reaction and the remaining liquid became clear (Rowell, 1994). Then, 10 ml of CALGON (a dispersing agent = mixture of 5 g sodium hydroxide and 0.7 g anhydrous Sodium with 1 l distilled water) was added, which forms liquid that prevents the agglutination of particles. Afterwards, the sample was placed in 50 ml plastic tubes and put on a shaker overnight.

Measurements of the grain size was done using the Laser Diffraction Beckman Coulter LS13 320 equipment of the Geography department of QMUL. First, each pre-treated sample was put on a shaker again to loosen the settled sediment. Then it was poured into a small plastic container and a whirl added to keep the particles in suspension. Subsequently, with a plastic pipette the right amount of sample, which was calculated by the machine, was extracted and placed in glass tubes of the machine. The best fitting settings (flow speed, measuring time) had first to be tested before any measuring (20 min per sample) could start. Sometimes, the machine was not working

properly and some samples had to be run again. Also, several samples were done twice for the PSA calculations with the program GRADISTAT (Boltt, 2000).

2.6. Location and elevation measurements

In order to find the right position of samples or cores again in the field, it is important to know their exact location, and for calculating the Chart Datum (C.D.) the elevation is needed. The first attempt at measuring the position and elevation was done with a hand held Global Positioning System (GPS), but the accuracy was 3 m depending on the weather.

Next, an imaging station was used in combination with Global Mapper with reference elevations marked on the maps in Ordnance Datum (accuracy 1 m). For this the machine had to be placed on the reference points (fix point) and with a prism on a staff other locations could be measured using a laser. This was done for all marshes on the week long field trip (chapter 3) and some Tollesbury samples. The elevation data of each sample were calculate from Ordnance Datum with help of the Admiralty Tide Table (1977) into Chart Datum to get a better picture in what context they and therefore, the marsh surface is located between MHWST and MHWNT (chapter 6).

The last method involved two different d-GPS from Leica which were not available at an earlier date. Therefore, only at Tollesbury surface samples and core positions as well as transects and plant zonations were measured. Three transects were chosen, where the lowest (creek rim) and highest position of a marsh surface were measured in order to: first, compare if the elevation differences between high and low marsh is the same for the whole saltmarsh and second, estimate the angle in which the marsh plateau falls off towards the sea. As for the plant zones, three areas were chosen. The first one was around the half island where the seasonal study was conducted including the sea wall. There, of each zone *Elytrigia*, *Puccinellia*, *Atriplex*, *Salicornia* and creek rims, the upper and lower limit were measured. Only *Puccinellia* was always mixed with other plant species so that only single points could be measured. The second location was further on the marsh plateau where the same zones and limits were measured, minus *Elytrigia*. And the third location was towards the mid-outer section of the marsh measuring the mid marsh zone only. For the results of the transects and plant zones see chapter 6.

3. Study Sites

Chapter two focuses on the reasons for choosing the saltmarshes studied and gives a brief description of each, including their location, morphology, abundant plant species, geology and any other relevant factors (e.g. grazing).

3.1. Site locations

The macrotidal saltmarshes Allen & Pye (1992) classified are (1) open-coast, (2) back-barrier, (3) estuarine-fringing, (4) embayment, and (5) loch-(fjord-) head saltmarshes (chapter 1.1). We chose examples from some of these types, in different geographical areas and on isostatically rising and falling coasts.

Fifteen saltmarshes (figure 3.1) were chosen with the main site at Tollesbury, Essex, SE England, because of previous works (Janie, 2011) as well as its closeness and easy access. This marsh is a wave-sheltered estuarine fringing one. The Gann was chosen because it is used to teach saltmarsh succession by the Field Studies Council (FSC) and lies on the west coast of Wales. The Two Tree Island sites is an open coast marsh in the SE and we have previous data (Janie, 2011). The criteria for choosing these sites were based on (i) their location on tectonically rising or subsiding coasts and relative sea-level history, (ii) permission, easy accessibility, (iii) available background literature e.g. data on ecology, palaeontology, sedimentation and age dating. The Western Yar Estuary was chosen due to previous ecological research on Ostracoda there.

(i) Salt marsh sites were chosen north and south of the isostatic fulcrum (chapter 1.4) considering the relative sea-level history for each site. Then saltmarshes were examined on Google maps and 13 sites were decided on initially.

(ii) For the sites permission in England, local branches of Natural England were contacted, if necessary the landowner also had to be asked separately. The same procedure was conducted with Scottish Natural Heritage for the Scotland sites. The relatively easy access from the roads was also important considering the equipment that had to be carried onto the marshes (by low tide). This led to 9 study sites including the already extracted sediment core from Holkham which was sampled by the British Geological Survey (BGS).

(iii) Additionally, if possible, existing data for each locality was collected including marsh transects listing meiofauna and plants. Further, sediment cores, age dates and specific site dependent tectonic movements or relative sea-level changes were used from literature (Jardine, 1975; Horton & Edwards, 2006a).

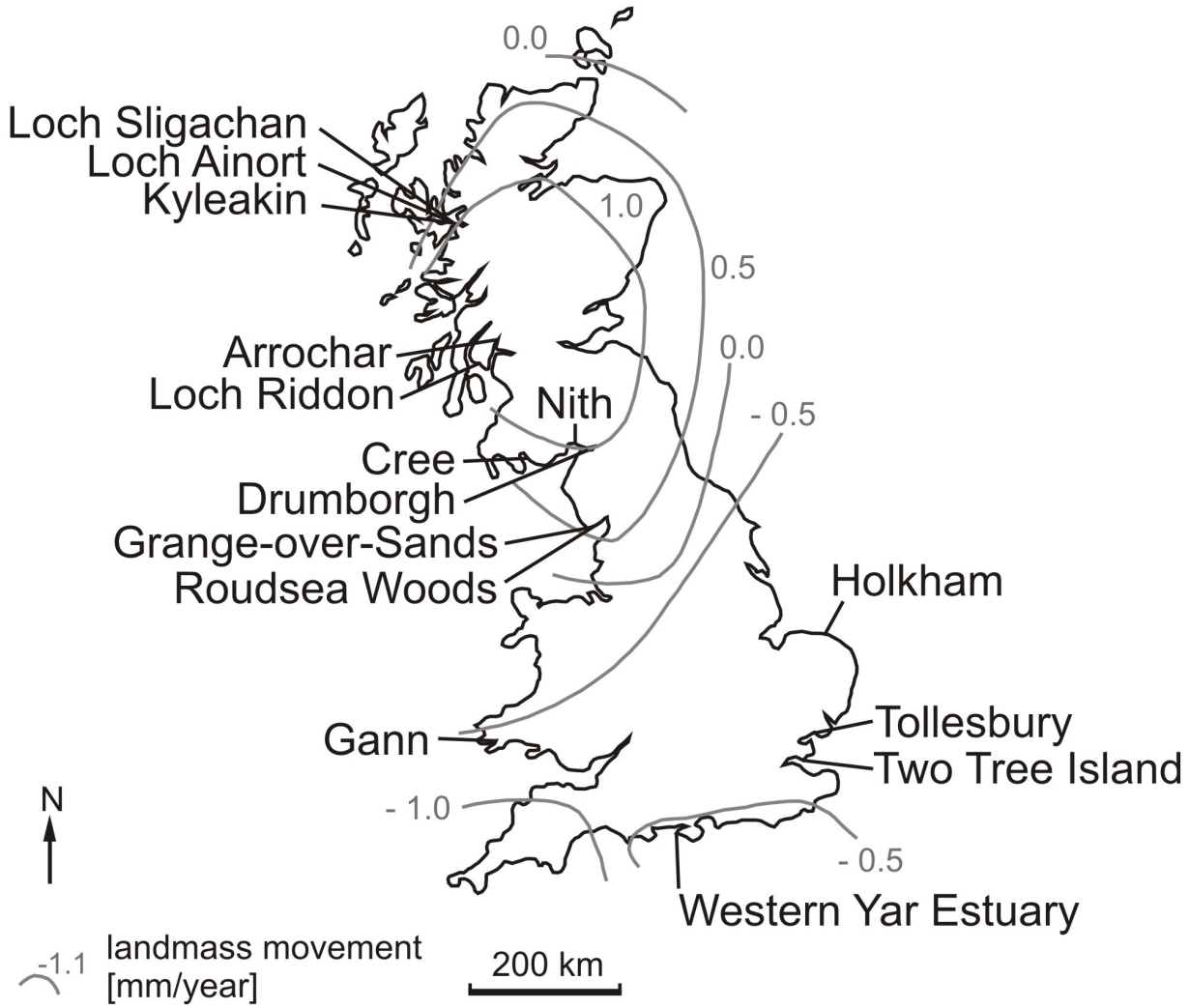


Figure 3.1.: All saltmarsh sites located around the UK. The grey lines represent the tectonic rebound of the land mass after the Last Glacial Maximum (LGM). Positive numbers represent a rising of the land in mm per year and the negative numbers represent tectonically subsidence in mm per year (Horton & Edwards, 2006a).

During the field trip, two more sampling sites were added: Arrochar and Loch Sligachan which are both loch-head saltmarshes. However, this spontaneous decision led to sampling during mid tide. This means that 11 sampling sites were visited during the field trip, and a total of 15 sites in the UK were sampled. All sampling dates, including sample numbers and descriptions, can be found in table 3.1.

Table 3.1.: This table lists the sampling location (and name) with their sampling date. Also, details are given about the number of samples (ss = surface sample, sc = sediment core) and if any GPS data were collected. Descriptions can be found under other data.

Sampling location (name)		**sampling date**	**samples**	**description**
Gann	(G)	1^{sh} September 2011	4 ss and 3 sc	
Tollesbury	(T I)	20^{th} October 2011	4 ss	
Two Tree Island	(TTI)	24^{th} November 2011	5 ss and 1 sc	
Tollesbury	(T II)	9^{th} December 2011	8 ss and 1 sc	
Tollesbury	(T III)	16^{th} February 2012	17 ss	seasonal study
Tollesbury	(T IV)	26^{th} April 2012	17 ss	seasonal study
Tollesbury	(T V)	29^{th} June 2012	17 ss	seasonal study
British Geological Survey	(Hol)	24 July 2012	1 sc	resampling NNC 17
Grange-over-Sands	(GoS)	25^{th} July 2012	4 ss and 1 sc, GPS	
Roudsea Wood	(RW)	25^{th} July 2012	4 ss and 1 sc, GPS	
Drumborgh	(DB)	26^{th} July 2012	4 ss and 3 sc, GPS	
Nith	(NI)	27^{th} July 2012	3 ss and 2 sc, GPS	
Cree	(CR)	27^{th} July 2012	3 ss and 2 sc, GPS	
Loch Riddon	(LR)	28^{th} July 2012	4 ss and 3 sc, GPS	
Arrochar	(AR)	29^{th} July 2012	1 ss and 2 sc, GPS	
Loch Ainort	(LA)	29^{th} July 2012	1 ss and 2 sc, GPS	
Loch Sligachan	(LS)	29^{th} July 2012	1ss and 1 sc, GPS	
Kyleakin	(KY)	30^{th} July 2012	4 ss and 2 sc, GPS	
Tollesbury	(T VI)	30^{th} August 2012	17 ss	seasonal study
Tollesbury	(T VII)	25^{th} October 2012	17 ss and 1 sc	seasonal study
Tollesbury	(T VIII)	2^{nd} November 2012	1 sc	dating (^{14}C & OSL)
Tollesbury	(T IX)	19^{th} December 2012	17 ss and GPS	seasonal study
Tollesbury	(T X)	27^{th} February 2013	17 ss	seasonal study

Continued on next page

Table 3.1 – continued from previous page

Sampling location (name)		sampling date	samples	description
Isle of Wight	(IW I)	18^{th} April 2013	13 ss	Ostracod study
Tollesbury	(T XI)	30^{th} April 2013	17 ss	seasonal study
Tollesbury	(T XII)	10^{th} May 2013	6 ss and 1 sc	salt pan samples & core
Tollesbury	(T XIII)	8^{th} July 2013	1 sc	dating (^{137}Cs & ^{210}Pb)
Tollesbury	(T XIV)	29^{th} August 2012	GPS	transects, plant zones
Isle of Wight	(IW II)	18-19^{th} February 2014	27 ss and 1 sc	Ostracod study, resampling

3.2. Site descriptions

The study sites were visited once, apart from the main site Tollesbury where a seasonal study was conducted and the Western Yar Estuary which focused on studying Ostracoda life cycles only. For a list of all plants that were encountered, see appendix A. Following are detailed descriptions of all sites, including maps and photos.

3.2.1. Tollesbury (T)

The main study site is north of Tollesbury in Essex, (figure 3.2) in the Blackwater Estuary, east site of the re-alignment site (51°45'53.40" N, 0°50'33.57" E) within the Blackwater Estuary Site of Special Scientific Interest (SSSI) of Natural England (NE). Its total estuary area is 5184 ha (Estuary, 2002) with a changing saltmarsh area of 880.2 ha in 1973 to 683.6 ha in 1998 regarding (Cooper et al., 2001). The mean spring tidal range is 4.7 m. The plateau-like saltmarsh is mature and intersected with complex dendritic channels up to 2 m deep and is backed by a sea wall built in the 1700s to protect the lower hinterland from the tides. The underlying geology consists of the London Clay Formation, a sedimentary bedrock formed of clay, silt and sand, covered by beach and tidal flat deposits (clay, silt, sand) (British Geological Survey, 1832; Garbutt et al., 2006). The plant species dominating the high marsh is *Elytrigia atherica*, for the mid marsh *Puccinellia maritima* with *Atriplex portulacoides* bordering the creeks (Hughes et al., 2009). Pioneer zone (low marsh) species *Salicornia europaea*, and *Suaeda maritima* are scarce and usually on creek edges and fallen eroded sediment blocks together with the filamentous green algae *Ulva* sp. (*Enteromorpha*). *Spartina anglica* is found sporadically through the marsh plateau. Dark green cyanobacteria mats occur further down the creek walls and at the bottom of the creeks brown diatomaceous films were sometimes seen (figure 3.3). The saltmarsh is not grazed by livestock but in winter grazing geese (Brent and Greylag) were occasionally observed. Sediment cores of 2.5 m (TCE, *Elytrigia*), 4 m (c II, age dating),

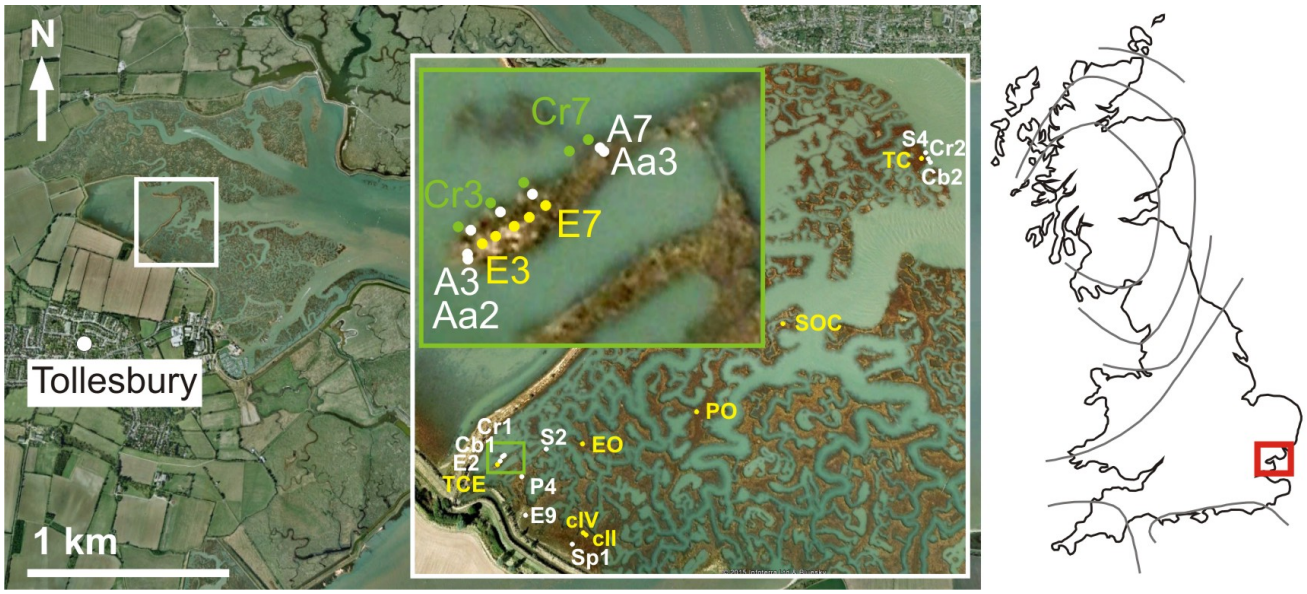
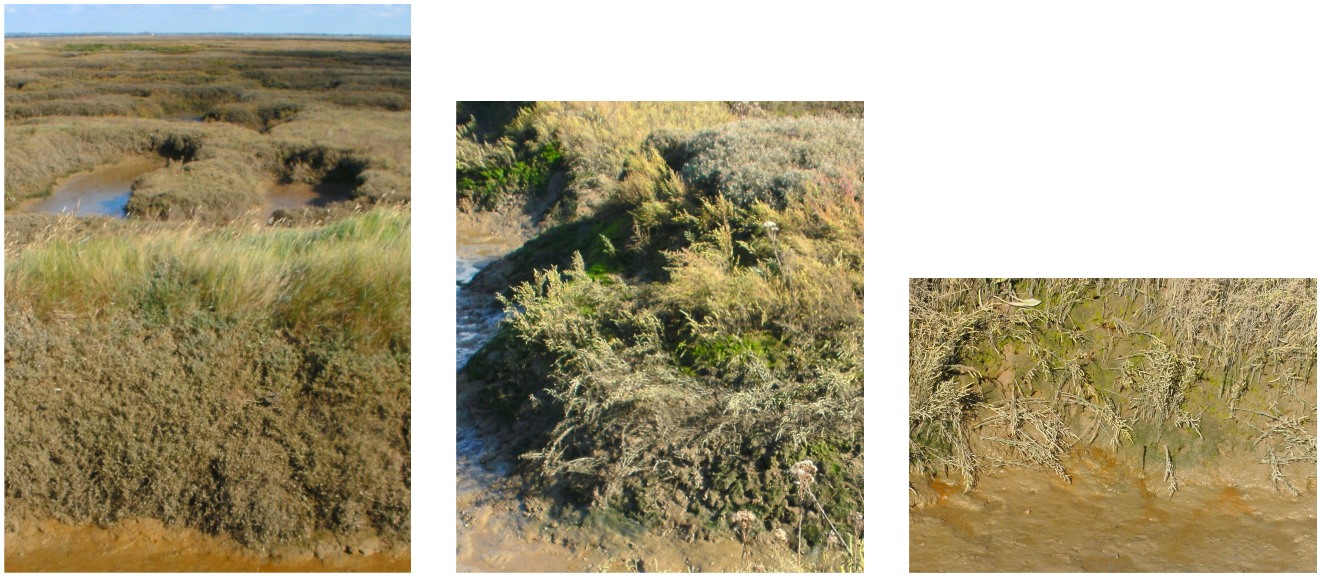


Figure 3.2.: Left: An aerial photograph (modified Google Earth) showing the location of Tollesbury with the sampled saltmarsh to the north (white box). In it, surface samples (white) and sediment cores (yellow) are indicated, including those from a masters project (EO, PO, SOC). The magnification of the marsh (green box) shows the seasonal study samples, where from the high marsh (E3 to E7 in yellow), mid marsh (A3 to A7 including Aa2 and Aa3 in white) and low marsh (Cr3 to Cr7 in green) where collected every two month for over a year. For the exact locations of the sampling spots see table C.1. Right: Location of the Tollesbury study site (red box) in the UK.



(a) Saltmarsh surface (b) Mid-low marsh vegetation (c) Creek slope

Figure 3.3.: Photos showing Tollesbury saltmarsh with its typical vegetation and creeks by low tide (a) Saltmarsh surface: showing in front high marsh (tallest grass in light brown), then underneath mid marsh (*Atriplex* with overgrown algae in brown) (b) Mid-low marsh vegetation: top right shows mid marsh (*Atriplex* in dark green) followed by low marsh (*Salicornia* in light brown-yellow), and (c) Creek slope: shows the low marsh plant *Salicornia* (brown-yellow) followed underneath by the algae *Ulva* (light green), then cyanobacteria (dark green) and at the creek bottom Diatoms (brown-red patches).

5 m (TC) *Puccinellia*) and 1 m (c IV, age dating) lengths were extracted as well as several surface samples from all saltmarsh zones including the creek rim and bottom, representing the mudflat, were collected. Further, three sediment cores (EO, PO, SOC), ranging from 3.33 m over 2.91 m to 2.75 m depths, with their Foraminiferal assemblages were available from a master project (Janie, 2011).

3.2.2. Two Tree Island (TTI)

Two Tree Island is near the mouth of the Thames Estuary, south of Leigh-on-Sea, Essex, (figure 3.4). The saltmarsh sampled is to the east of the south car park (51°32'08.38" N, 0°37'50.34" E) and within the Leigh National Nature Reserve and the Benfleet and Southend Marshes SSSI. The saltmarsh has a plateau with a cliff up to 1.5 m high fronting the sandflats which is occasionally slumped. Near Southend-on-Sea the maximum tidal range is 5.73 m (Tide-forecast, 2016). Two Tree Island is a 257 ha large island. The underlying geology consists of the London Clay Formation with sediments from beach and tidal flats (clay, silt and sand) deposited on top (British Geological Survey, 1832). The plant species are similar to those at Tollesbury (figure 3.5). The saltmarsh is not grazed by livestock but in winter large flocks of Brent geese, attracted to the site by *Zostera* spp. on the sandflats roost and graze the marsh when the flats are covered by the tide. One 5 m deep sediment core (TCP) was extracted from the *Puccinellia* zone with surface samples taken from low (*Salicornia*), mid (*Puccinellia*) and high (*Elytrigia*) marsh areas. Foraminiferal assemblage data from a 4 m deep sediment core (Core from

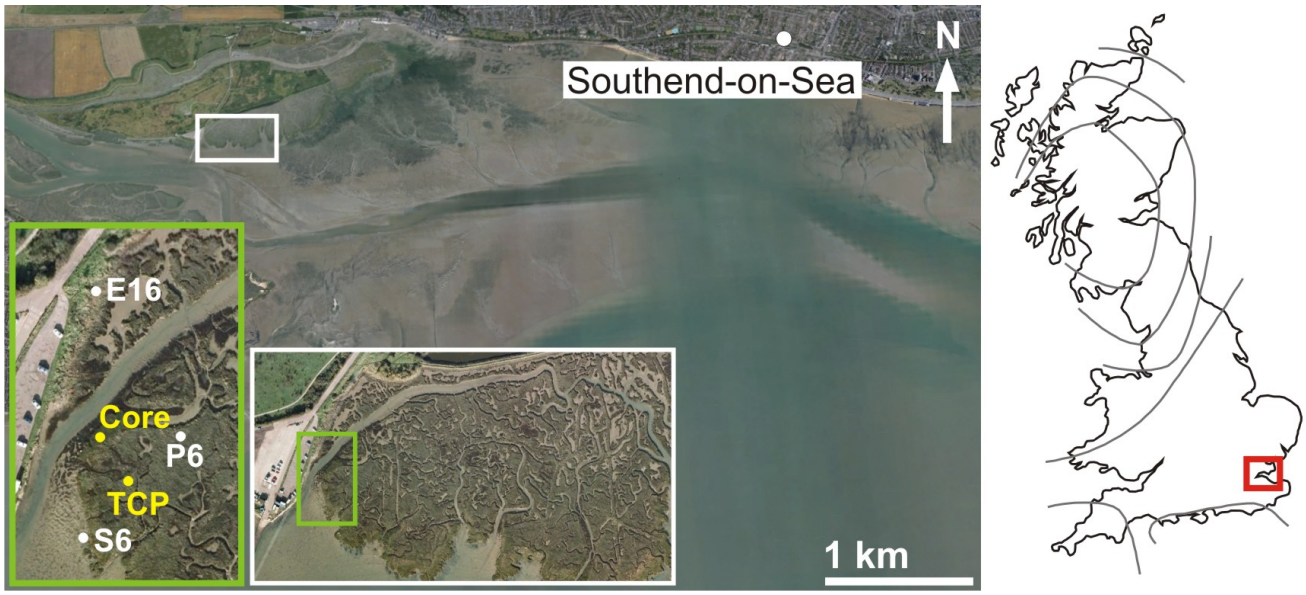


Figure 3.4.: Left: An aerial photograph (modified Google Earth) showing Southend-on-Sea with Two Tree Island saltmarsh to the west (white box). The green box represents a magnified photo of the marsh where surface samples (white) and the sediment core (yellow) are indicated (E 16 = *Elytrigia*, P 6 = *Puccinellia*, S 6 = *Salicornia*, TCP = *Puccinellia* core, Core = *Puccinellia* / *Atriplex* core from master project). No GPS data of the sampling spots exist. Right: Location of the Two Tree Island study site (red box) in the UK.

Puccinellia / *Atriplex* zone) was also available from a previous master study (Palmisano, 2010).

(a) Saltmarsh surface

(b) Mid-low marsh with creek

Figure 3.5.: Photos showing Two Tree Island saltmarsh with its typical vegetation by low tide (a) Saltmarsh surface: showing the marsh plateau with its cliff in front of it, the area is covered by *Puccinellia*, and (b) Mid-low marsh with creek: from the creek upwards are growing *Salicornia* (green plants) and algae intermixing, and *Puccinellia* (brown plants) which is dominating the marsh vegetation.

3.2.3. Western Yar Estuary (IW)

This site is located on the western side of the Isle of Wight, south England and can be divided into two sampling areas: north and south. The saltmarshes in the Western Yar Estuary are a SSSI. The maximum tidal range at Portsmouth is 4.89 m (Tide-forecast, 2016).

The northern site was south of Yarmouth harbour (figure 3.6), on the east site of the River Yar (50°42'01.86" N, 1°29'57.60" W). The saltmarsh here is a plateau approximately 50 cm above the mudflat with few intersecting creeks. The underlying bedrock consists of the sedimentary Headon Beds and Osborne Beds (clay, silt and sand) which is covered by tidal flat deposits (clay, silt) (British Geological Survey, 1832) that fills a Holocene drowned valley (Hopson, 2011). The most common plants are *Elytrigia atherica* in the high marsh and *Puccinellia maritima* and *Atriplex portulacoides* in the mid-marsh plateau. On the seaward edges of the plateau, dead *Spartina* were covering the bare mud before the cliff falls off. The pioneer zone consists of *Salicornia europaea* and *Spartina anglica*. This zone is mostly on the marsh plateau instead on slumped down sediment blocks observed at other marshes, e.g. Tollesbury. Also, a die-back of *Spartina* was observed (figure 3.7). 13 surface samples were collected from the marsh aera in April 2013. Samples were extracted from the high-mid (*Puccinellia* and *Atriplex*, Mix 1 and Mix 2), mid (*Atriplex*, Ai 1, Ai 2, Ao 1 and Ao 2) with salt pan (SP) and alge samples (Aos 1 and Aos 2), and low marsh (*Spartina*, L 1 and L 2). In February 2014, a 3.9 m deep sediment core was extracted

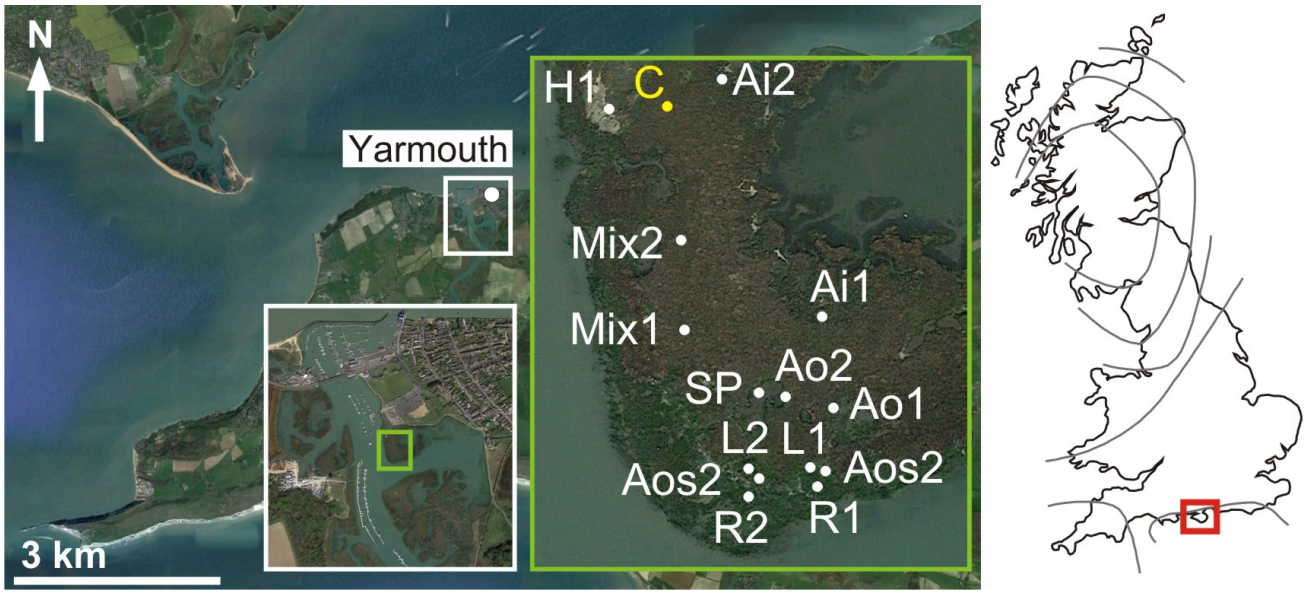


Figure 3.6.: Left: An aerial photograph (modified Google Earth) showing the location of Yarmouth and the northern sampling area of Western Yar Estuary (white box). The green box represents a magnified image of the surface samples (white) and the sediment core (yellow). In total 14 surface samples (including resampling) were collected: H 1 = high marsh, R 1 = marsh rim 1, R 2 = marsh rim 2, Aos 1 = algae on sediment 1, Aos 2 = algae on sediment 2, L 1 = low 1, L 2 = low 2, SP = salt pan, Ao 1 = outer *Atriplex* 1, Ao 2 = outer *Atriplex* 2, Mix 1 = mid marsh 1, Mix 2 = mid marsh 2, Ai 1 = inner *Atriplex* 1, Ai 2 = inner *Atriplex* 2. No GPS data of the sampling spots exist. Right: Location of the northern study site of the Western Yar Estuary (red box) in the UK.

(a) Saltmarsh surface (b) Mid-low marsh vegetation (c) Pioneer zone

Figure 3.7.: Photos showing the saltmarsh of the northern study area of the Western Yar Estuary with its typical vegetation by low tide: (a) Saltmarsh surface: is covered by a mix of *Elytrigia* (tall brown plants), *Puccinellia* (short brown plants), *Atriplex* (dark green plants) (b) Mid-low marsh vegetation: vegetated by *Puccinellia* (brown-yellow plants) and *Atriplex* (dark green plants) that grows nearer the creek and algae (light green), and (c) Pioneer zone: shows the bare mud before the cliff of the marsh falls off, vegetated by *Spartina* and algae (light green).

from the plateau together with a high marsh sample (*Elytrigia*, H 1) as well as a resampling of 6 surface samples was done: R 1 = R 3, R 2 = R 4, Aos 1 = Aos 3, Aos 2 = Aos 4, Mix 1 = Mix 3, Mix 2 = Mix 4 (see table B.5).

The southern study site (figure 3.8) in the Western Yar Estuary is on the eastern side of the River Yar east of Freshwater (50°41'00.16" N, 1°30'25.13" W). The relatively small marsh plateau has a shallow cliff approximately 15 cm high. Few small creeks are orthogonal to the saltmarsh. Whereas, the northern site has a more marine influence, the southern site is influenced by freshwater, due to a "base-rich water welling up from the chalk aquifer" (Natural England, 1987). There are no sea walls and the high marsh, dominated by *Phragmites australis* which indicates a freshwater influence, gradually merges with the terrestrial vegetation including oak trees. *Spartina anglica* dominates the pioneer zone above which is *Atriplex portulacoides*. It dominates along the creeks, and *Puccinellia maritima* intermixes with *Phragmites*. The marsh surface has leaf litter from the trees Both sampling site are ungrazed (figure 3.9). The underlying geology consists of the sedimentary Bracklesham Group and Barton Group (clay, silt, sand) with tidal flat deposits (clay, silt) on top which fills the continuing drowned valley (British Geological Survey, 1832). For the Ostracoda studies, seven surface samples were taken from the different marsh zones including leaf litter (mostly oak leaves, samples HL 1 and HL 2). The samples included the mid-high (*Puccinellia* = Mix 6), mid (*Atriplex*) with algae samples (Ao 5 and Aas 5), as well as low marsh (*Spartina* = L 5). Furthermore, a surface sample from the marsh cliff (R 5) was also collected.

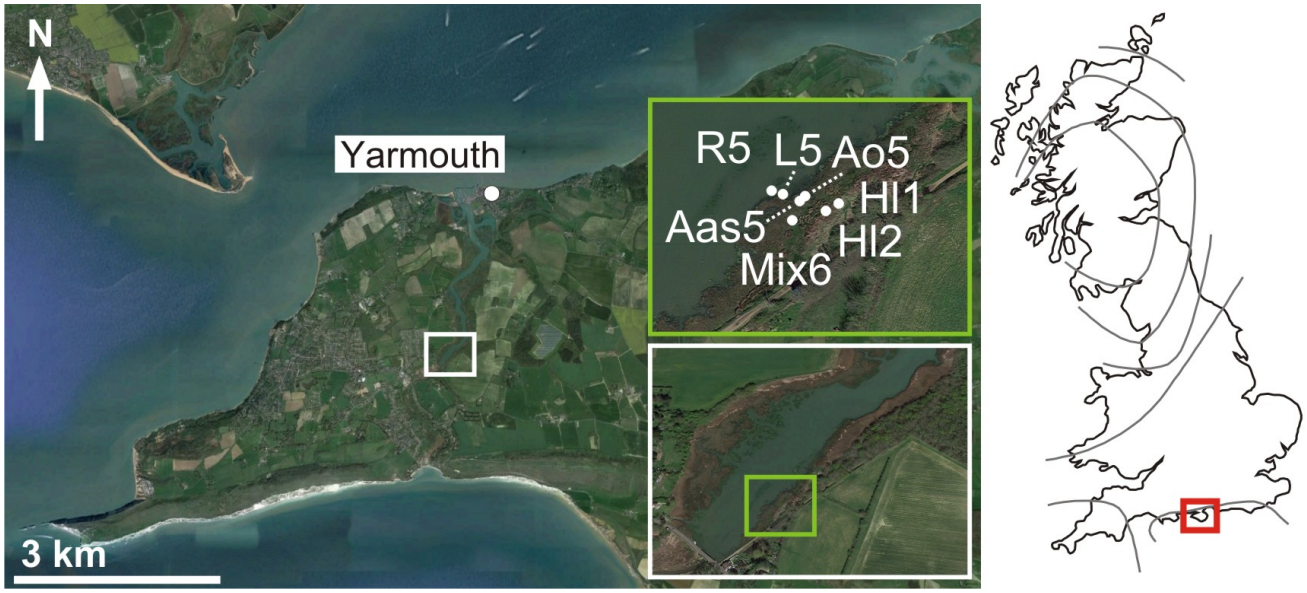


Figure 3.8.: Left: An aerial photograph (modified Google Earth) showing the location of Yarmouth. The southern study site of the Western Yar Estuary is indicated by the white box. The green box shows an magnified photo of the marsh including all surface samples (white). Seven samples were collected: R 5 = rim, L 5 = low, Aas 5 = *Atriplex* algae, Mix 6 = mid marsh, Hl 1 = high leaves (sediment), Hl 2 = high leaves. No GPS data of the sampling spots exist. Right: Location of the southern study site of the Western Yar Estuary (red box) in the UK.

(a) Saltmarsh (b) High-low marsh (c) Low marsh

Figure 3.9.: Photos showing the saltmarsh of the southern study area of the Western Yar Estuary with its typical vegetation by mid tide (a) Saltmarsh: showing the small stripe of the saltmarsh plateau (b) High-low marsh: the vegetation zones are shown from *Spartina* (brown plants) in front to *Atriplex* (dark green) to *Puccinellia* and *Phragmites* (light brown taller plants) with an oak tree in the background, and (c) Low marsh: sampling bags in front placed between *Spartina* (brown plants) and towards the mud patches of algae (black).

3.2.4. Gann (G)

The saltmarsh is on the west site of the Gann Estuary (figure 3.10) that discharges into Milford Haven north of Dale in Pembrokeshire, south-west Wales (51°43'14.66" N, 5°10'01.48" W). The 31.5 ha saltmarsh (Headley & Sale, 1999) is a plateau with a few creeks. The maximum tidal range at Milford Haven is 7.82 m (Field Studies Council, 2008; Tide-forecast, 2016). Inside the estuary the saltmarsh terminates in a cliff of varied height but at the entrance the marsh slopes gently to the sandflat with a small area of pioneer marsh dominated by *Salicornia*. The sediment has a higher proportion of sand than the estuarine marshes of Essex. The bedrock is a mix of sedimentary, igneous and metamorphic rocks from the Llandeilo Flags Formation (tuffaceous-mudstone) and the Skomer Volcanic Group (rhyolite and metafelsite) that is covered by tidal deposits (clay, silt, sand) (British Geological Survey, 1832). The vegetation shows a clear zonation with *Elytrigia atherica* in the high marsh, *Puccinellia maritima* and *Atriplex portulacoides* dominate the mid marsh plateau and *Salicornia europaea* where is low marsh (figure 3.11). The area has never been grazed. Three approximately 1 m deep sediment cores of marsh sediment, down to the underlying gravels, were collected from high (*Puccinellia* zone, T 2), mid (*Puccinellia* / *Atriplex* zone, T 3) and low marsh (*Salicornia* zone, T 4) together with four surface samples, with an additional one from the high marsh from the same areas.

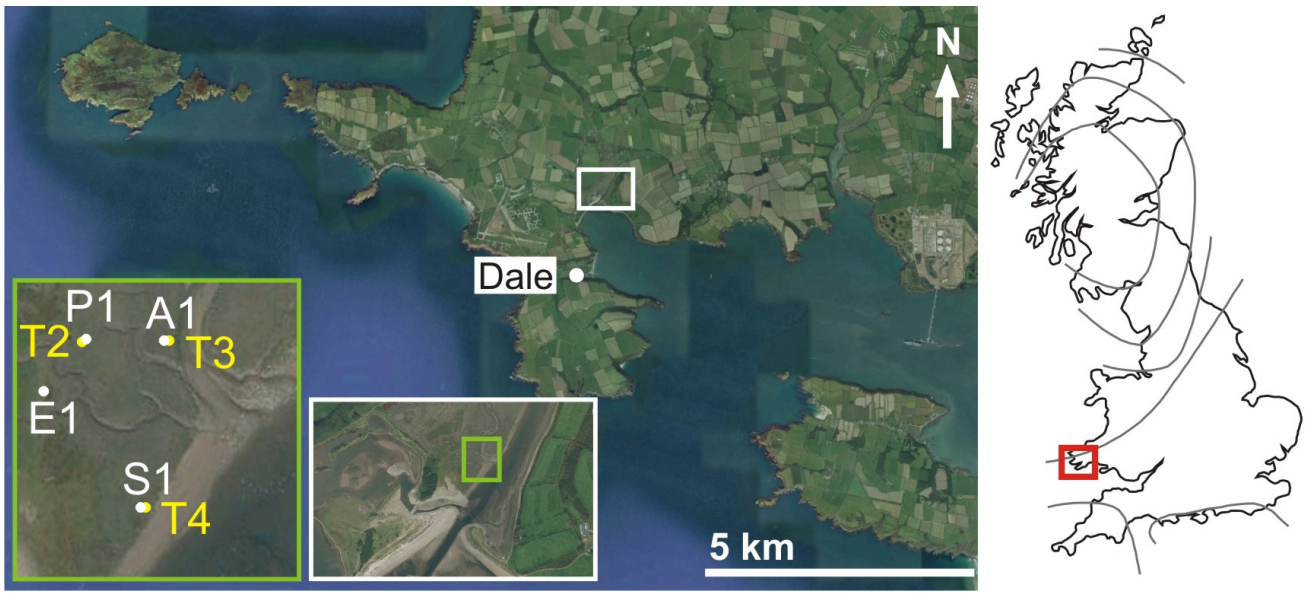


Figure 3.10.: Left: An aerial photograph (modified Google Earth) showing the location of Dale, where the sampled saltmarsh is indicated by the white box to the north-east. The green box represents a magnified photo of the marsh, showing the surface samples (white) and sediment core (yellow) spots (E 1 = *Elytrigia*, P 1 = *Puccinellia*, A 1 = *Atriplex*, S 1 = *Salicornia*, T 2 = core 1, T 3 = core 2, T 4 = core 3). No GPS data of the sampling spots exist. Right: Location of the Gann study site in the UK.

(a) Saltmarsh surface (b) Mid marsh (c) Low marsh

Figure 3.11.: Photos showing Gann saltmarsh with its typical vegetation and creeks by low tide (a) Saltmarsh surface: showing the marsh plateau with creek and its typical vegetation (b) Mid marsh: to the left grows *Atriplex* (silvery, dark green plants) and the rest of the marsh is covered by *Puccinellia* (brown green plants) which are typical for the mid marsh zone, and (c) Low marsh: pioneer plant *Salicornia* growing in front of marsh plateau which is covered in the background by *Atriplex* along the creek.

3.2.5. Grange-over-Sands (GoS)

North-east of Grange-over-Sands lies the Kent Estuary opening into the area of Morecambe Bay, south Cumbria in north-west England with its mudflats and saltmarshes (figure 3.12). The sampling location is south of the Grange-over-Sands Golf Club and east of Home Island (54°11'56.98" N, 2°53'08.15" W). This island became part of the mainland when the Ulverston-Lancaster railway (Arnside viaduct) was completed in 1857 and the

River Winster was channelled (Horne, 1975). Between Meathop and Holme the marsh area varied between 55 and 69 ha between 1845 to 1967 (Gray, 1972). This area belongs to the Morecambe Bay SSSI. It is a relatively new marsh forming here in front of the sea wall built to reclaim the land which is now a golf course and to carry the railway line along the estuary. This saltmarsh plateau terminates in a shallow 10 cm heigh cliff where it joins the sandflat. There are relatively few simple creeks and a few salt pans. The marsh is situated in the top 2.5 m of the tidal range which is 9.5 m for Morecambe Bay (Gray, 1972). The sedimentary bedrock is formed of the Yoredale Group consisting of mud-, silt- and sandstone which are covered by tidal deposits (clay, silt) (British Geological Survey, 1832). The plants on the marsh surface show a zonation where *Puccinellia maritima* dominates the marsh plateau and intermixes with *Festuca rubra* in higher areas. *Spartina anglica* occurs at the lowest levels in front of a small cliff. The marsh is grazed by sheep that leave a uniform trimmed vegetation (figure 3.13). One 85 cm deep sediment core was extracted from the mid marsh plateau. Three surface samples were collected from the vegetated marsh (high, mid and low) and one from a salt pan.

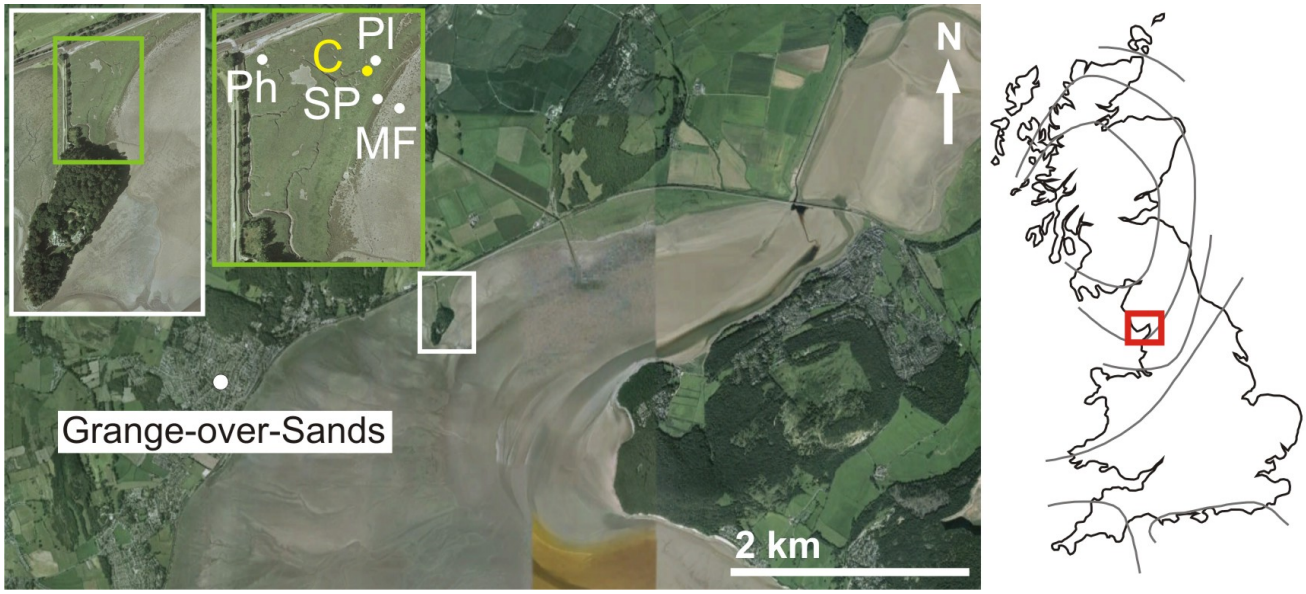


Figure 3.12.: Left: An aerial photograph (modified Google Earth) showing the location of Grange-over-Sands. To the north-east lies the sampled saltmarsh (white box) near Home Island. The green box represents a magnified photo of the marsh indicating the surface samples (white) and the sediment core (yellow) spots (Ph = *Puccinellia* high, Pl = *Puccinellia* low, SP = salt pan, MF = mudflat, C = core). For the exact locations of the sampling spots see table C.4. Right: Location of the Grange-over-Sands study site (red box) in the UK.

(a) Saltmarsh surface (b) Mid-low marsh vegetation (c) Low marsh

Figure 3.13.: Photos showing Grange-over-Sands grazed saltmarsh with its typical vegetation and creeks by low tide (a) Saltmarsh surface: showing a water filled salt pan and nearly straight creeks that dissect the marsh surface which is covered by *Puccinellia* (b) Mid-low marsh vegetation: seawall in the background followed by *Puccinellia* (green) and *Spartina* (darker green) after a small cliff, and (c) Low marsh: *Spartina* with patches of mud (salt pan).

3.2.6. Roudsea Woods (RW)

The saltmarsh within the Roudsea Wood Nature Reserve lies south-east of Greenodd in the Leven Estuary, south Cumbria in north-west England (figure 3.14). The sampling area is located on the east site of the River Leven (54°13'42.03" N, 3°01'58.64" W) where the marsh has a width of approximately 200 m. In the northern part of the sampling area the River Leven cuts into the marsh surface causing slumping and the creation of a 2 m high cliff. To the south the cliff is approximately 50 cm in height with little slumped marsh edge on the mudflat. The tidal range is 8.4 m (Horton & Edwards, 2006b). The saltmarsh generally has formed a plateau with intersecting few smaller creeks. The sedimentary bedrock is formed of the Bannisdale Formation consisting of interbedded silt- and mudstone. These rocks are now covered by tidal river and creek deposits (silt, sand) (British Geological Survey, 1832). Rocks from the underlying geology emerge occasionally through the marsh surface. The vegetation shows a less structured plant zonation with *Phragmites australis* appearing at the upper edges of the marsh indicating freshwater influence, with *Elytrigia atherica* in patches on the highest ground. The mid marsh vegetation is dominated by *Puccinellia maritima* intermixed with *Agrostis stolonifera* that dominates the low marsh. No pioneer zone vegetation was present and the marsh is ungrazed (figure 3.15). Two sediment cores with depths of 1.7 m and 2.1 m from the mid marsh were collected together with four surface samples, from the high, mid and low marsh and the mudflat.

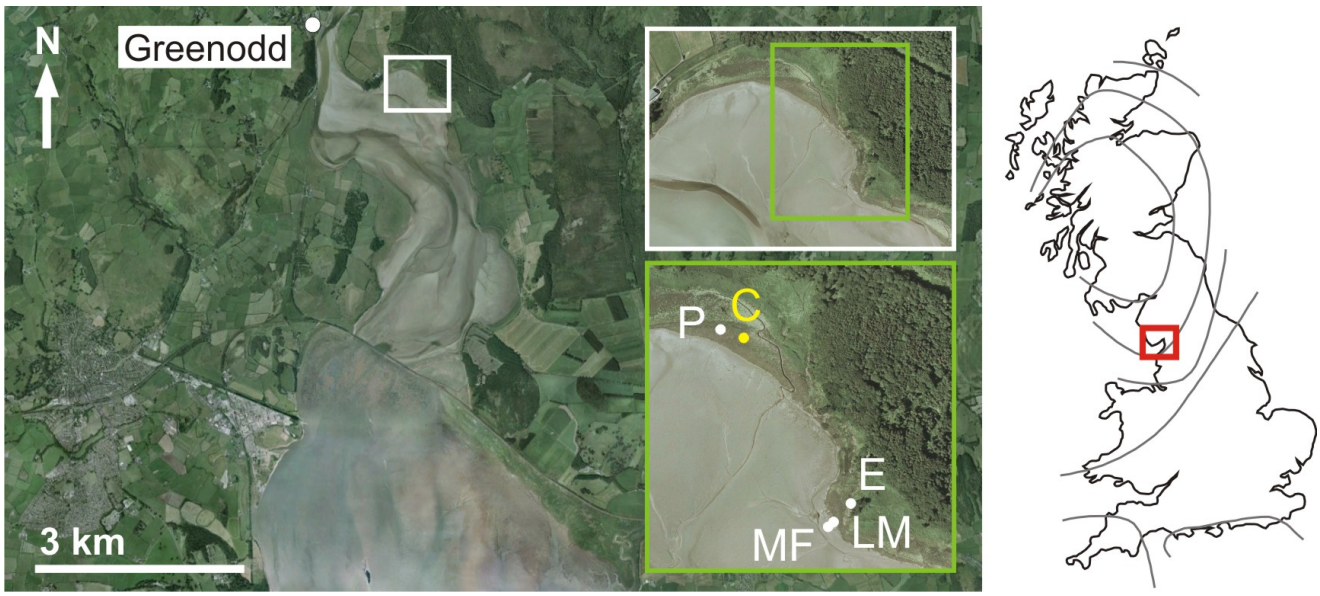


Figure 3.14.: Left: An aerial photograph (modified Google Earth) showing the location of Greenodd. The sampled Roudsea Woods saltmarsh lies to the south-east, indicated by the white box. The green box represents a magnified photo of the marsh showing the surface samples (white) and sediment core (yellow) locations (E = *Elytrigia*, P = *Puccinellia*, LM = low marsh, MF = mudflat, C = core). For the exact locations of the sampling spots see table C.5. Right: Location of the Roudsea Woods study site (red box) in the UK.

(a) Saltmarsh surface (b) Mid marsh (c) Low marsh

Figure 3.15.: Photos showing the Roudsea Woods saltmarsh with its typical vegetation by low tide (a) Saltmarsh surface: showing plant zonation with *Phragmites* (dark green plants to the right) in the background followed by *Elytrigia* (brown plants) and in front of it a mix of *Puccinellia* together with *Agrostis* (b) Mid marsh: eroding cliff, created by the river Leven, with *Puccinellia* and *Agrostis* on the marsh plateau, and (c) Low marsh: showing colonised mud with *Spartina* and a cliff separating the marsh plateau.

3.2.7. Drumburgh (DB)

The sampled saltmarsh lies within the Westfield marsh, north-west of Drumburgh, Cumbria (figure 3.16) on the south side of River Eden (54°56'19.50" N, 3°09'44.60" W) that discharges into upper Solway Flats and Marshes

SSSI. The saltmarsh forms three distinct terraces. The highest terrace is separated from the middle terrace by a cliff of 40 to 50 cm in height, and the second terrace is separated from the third by a cliff 80 to 90 cm high. The exposed sediment of the cliffs had a clear lamination of silt and sand layers each approximately 0.5 cm in thickness. There were few creeks. The tidal range is 8.4 m (Horton & Edwards, 2006b). The sedimentary underlying geology consists of the Mercia Mudstone Group (mudstone with gypsum-stone and anhydrite-stone). The bedrock is covered by raised tidal flat deposits (silt, clay) and locally mixed with superficial deposits of the Gretna Till Formation (diamicton) (British Geological Survey, 1832). The saltmarsh vegetation showed a vertical zonation on the high, mid and low marsh terraces. The highest terrace plants were dominated by *Festuca rubra*, *Aster tripolium* and *Juncus gerardii*. *Agrostis stolonifera* was on the high and mid terraces, with *Armeria maritima* and *Glaux maritima* only on the mid terrace. Throughout the whole marsh *Puccinellia maritima* appears which is taking over and dominating the low marsh in front of the terraces. No pioneer zone (*Salicornia*, *Suaeda* or *Spartina*) vegetation was seen. The marsh is grazed by cattle and the vegetation was short at all elevations (figure 3.17). Four surface samples were taken, one from each terrace and the mudflat, and one sediment core from each terrace (to depths of 1 m, 2.1 m and 1 m respectively).

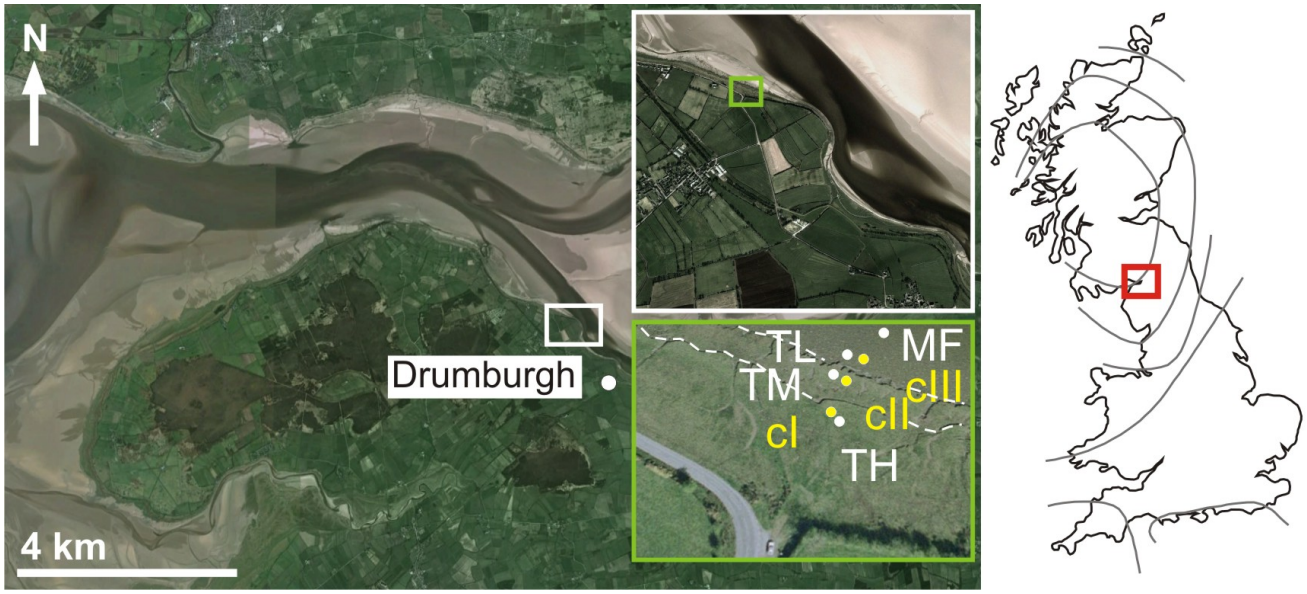


Figure 3.16.: Left: An aerial photograph (modified Google Earth) showing the location of Drumburgh, with the sampled saltmarsh in the white box. The green box is a magnified image of the marsh, indicating the sampling spots. The surface samples (white), sediment cores (yellow) and the two terrace rims (white dashed line) is shown there (TH = terrace high, TM = terrace middle, TL = terrace low, MF = mudflat, c I = core I, c II = core II, c III = core III). For the exact locations of the sampling spots see table C.6. Right: Location of the Drumburgh study site (red box) in the UK.

(a) Terraced saltmarsh

(b) High-mid marsh with salt pans

(c) Low marsh with cliff

Figure 3.17.: Photos showing the Drumburgh saltmarsh with its typical grazed vegetation and three terraces by low tide (a) Terraced saltmarsh: top terrace grazed by cows which is separated by a cliff from the middle terrace which also forms a cliff until it falls of onto the lower terrace (low marsh) (b) High-mid marsh with salt pans: in front top terrace (mixed *Festuca* and *Juncus*) with cliff and below middle terrace with water filled salt pans and vegetated with a mix of *Agrostis*, *Armeria* and *Glaux*, and (c) Low marsh with cliff: lowest terrace vegetated with a mix of *Puccinellia*, *Spartina* and *Salicornia* with bare mud and a cliff of the middle terrace in the background.

3.2.8. Nith (NI)

This saltmarsh is located on the east site of River Nith (54°58'47.44" N, 3°33'26.91" W) south of Glencaple, Dumfries and Galloway (figure 3.18), within the Upper Solway Flats and Marshes SSSI. The saltmarsh is terraced in some places with a 1.3 m high cliff and in others with a 40 cm on top of a 90 cm high cliff. The sediment shows a clear lamination of silt and sand layers approximately 0.5 cm thick. The terraced marsh is intersected by dendritic creeks approximately 1 m deep. The tidal range is 8.4 m (Horton & Edwards, 2006b). The sedimentary bedrock is formed of the Appleby Group (sandstone with subordinate breccia) which covered by saltmarsh deposits (clay, silt) (British Geological Survey, 1832). The marsh vegetation is ungrazed and divided into high marsh on the upper terrace dominated by *Puccinellia maritima*, *Agrostis stolonifera* and *Festuca rubra* and the lower marsh is dominated by *Bolboschoenus maritimus*. No pioneer zone vegetation was present (figure 3.19). Three surface samples were collected from each terrace, and a 1 m deep sediment core from the upper terrace and a 57 cm deep core from the low marsh.

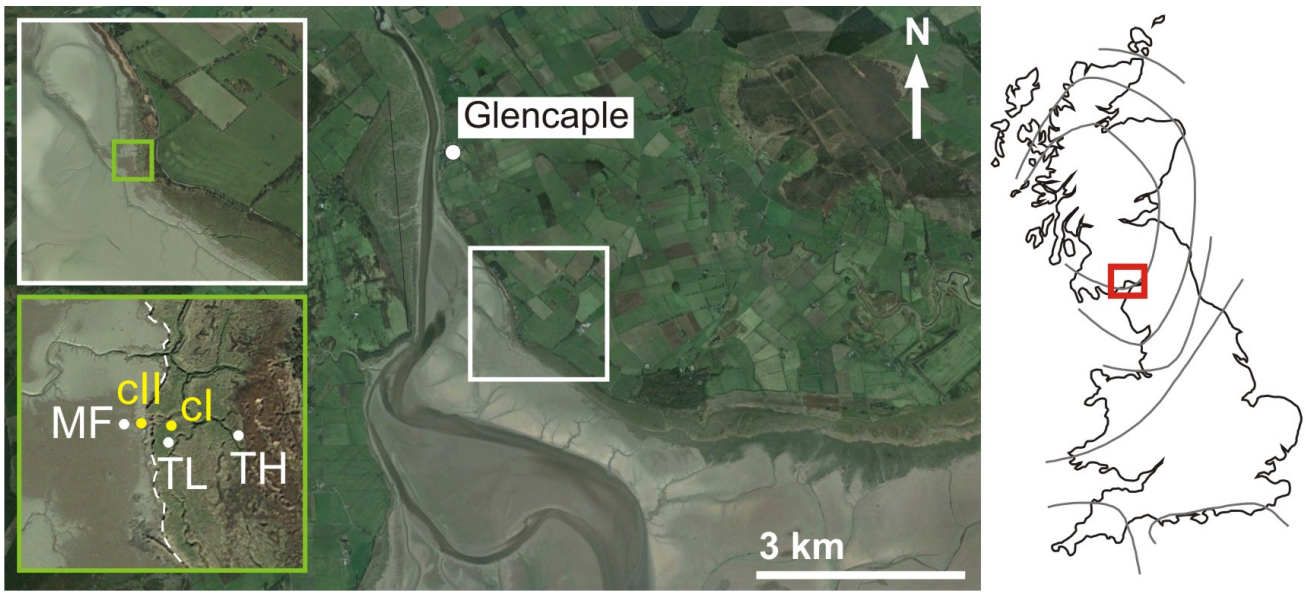


Figure 3.18.: Left: An aerial photograph (modified Google Earth) showing the location of Glencaple with the sampled Nith saltmarsh indicated by the white box. The green box represents a magnified image of the marsh with the surface (white) and sediment core (yellow) sampling spots (TH = terrace high, TL = terrace low, MF = mudflat, c I = core I, c II = core II). Also, the cliff which terminated the saltmarsh plateau is shown by the white dashed line. For the exact locations of the sampling spots see table C.7. Right: Location of the Nith study site (red box) in the UK.

(a) Terraced saltmarsh (b) Terraces with cliffs (c) Low marsh with cliff

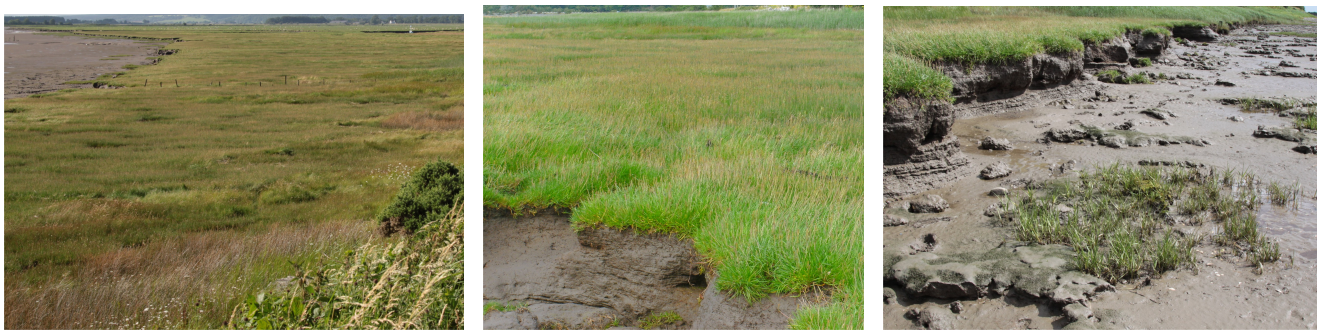
Figure 3.19.: Photos showing the Nith saltmarsh with its typical vegetation and one or two cliffs (terraces) by low tide (a) Terraced saltmarsh: the terraces were covered with a mix of *Puccinellia*, *Agrostis* and *Festuca* and each ends with a cliff, where *Bolboschoenus* was also growing (b) Terraces with cliffs: the marsh plateau formed at some locations one or two terraces with cliff(s), where the latter one could be bare mud, and (c) Low marsh with cliff: the few plants (*Bolboschoenus*) that were growing here appeared mostly patched.

3.2.9. Cree (CR)

The saltmarsh (figure 3.20) is on the east site of Cree Estuary south-west of Creetown, Dumfries and Galloway (54°53'36.60" N, 4°23'06.88" W) within the Cree Estuary SSSI. The saltmarsh is a plateau with a few intersecting

meter deep creeks and salt pans, terminating in an eroding cliff of 1 m hight with fallen sediment blocks on the flat below. The exposed sediment of the cliff is laminated silt and sand with layers of approximately 1 cm thickness. The tidal range is 8.4 m (Horton & Edwards, 2006b). The sedimentary bedrock consists of the Gala Unit 6 & 7 (wacke) with unlithified raised marine beach deposits (clay, silt, sand, gravel) (British Geological Survey, 1832). The saltmarsh vegetation on the plateau is grazed by sheep and dominated by *Puccinellia maritima* with patches of *Festuca rubra*, *Aster tripolium* and *Plantago maritima*. The single patches on the mudflat close to the cliff consists of *Puccinellia maritima* (figure 3.21). Surface samples were taken from the marsh on top of the terrace and one from the mudflat. Also, one 1.3 m deep sediment core from the marsh and a 80 cm core from the mudflat were collected.

Figure 3.20.: Left: An aerial photograph (modified Google Earth) showing the location of Creetown with the sampled saltmarsh indicated by the white box. The green box shows a magnified image of marsh surface with the surface (white) and sediment core (yellow) locations (sH = surface high, scI = surface core I, MF = mudflat, c I = core I, c II = core II). For the exact locations of the sampling spots see table C.8. Right: Location of the Cree study site (red box) in the UK.



(a) Saltmarsh plateau (b) Marsh vegetation (c) Low marsh

Figure 3.21.: Photos showing the Cree saltmarsh with its typical grazed vegetation and cliff by low tide (a) Saltmarsh plateau: overview of the marsh with cliff and bare mud in front (b) Marsh vegetation: shows a mix of *Puccinellia* with patches of *Festuca*, *Aster* and *Plantago*, but no clear zonation was visible, and (c) Low marsh: after the cliff, the mud was sparsely covered in patches of *Puccinellia*.

3.2.10. Arrochar (AR)

This small saltmarsh is at the head of Loch Long (figure 3.22) at Arrochar, Argyll and Bute (54°53'36.60" N, 4°23'03.88" W). The marsh plateau is approximately 50 cm above the mudflats and the ungrazed vegetation is largely *Puccinellia maritima*, *Agrostis stolonifera*, *Plantago maritima*, *Cochlearia anglica*, *Glaux maritima* and *Festuca rubra*. The marsh shows no zonation and no pioneer zone (figure 3.23). The maximum tidal range at

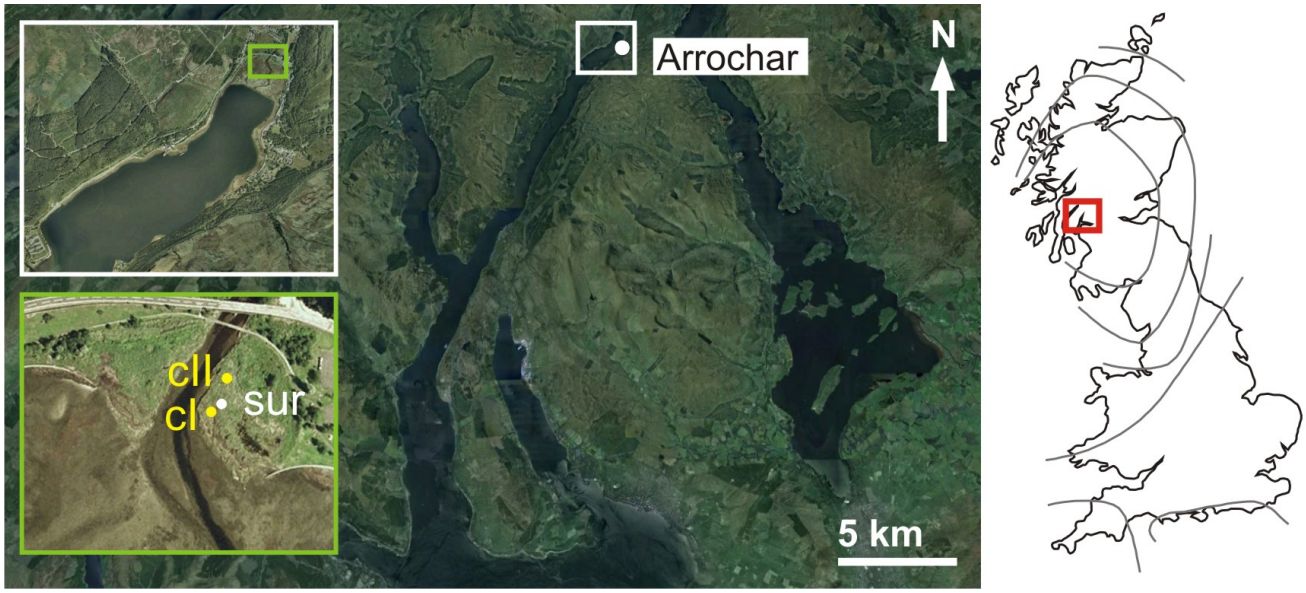


Figure 3.22.: Left: An aerial photograph (modified Google Earth) shows the location of Arrochar and the saltmarsh in the white box. The green box represents a magnified image of the marsh with the indicated surface (white) and sediment cores (yellow) positions (sur = surface, c I = core I, c II = core II). For the exact locations of the sampling spots see table C.9. Right: Location of the Arrochar study site (red box) in the UK.

Greenock (south of Arrochar) is 4.10 m (Tide-forecast, 2016). The underlying geology consists of the Beinn Bheula Schist Formation (psammite and pelite), a metamorphic bedrock with river terrace deposits (gravel, sand, silt, Clay) on top (British Geological Survey, 1832). One surface sample and two 50 cm deep sediment cores were collected.

(a) Saltmarsh (b) Marsh vegetation (c) Marsh edge

Figure 3.23.: Photos showing the saltmarsh near Arrochar (Loch Long) with its typical vegetation (a) Saltmarsh: head-loch marsh by mid tide (b) Marsh vegetation: consists a mix of *Puccinellia*, *Agrostis*, *Plantago*, *Cochlearia*, *Glaux* and *Festuca*, but no zonation was visible, and (c) Marsh edge: marsh by low tide where the lowest elevation was covered by *Puccinellia*.

3.2.11. Loch Riddon (LR)

The saltmarsh at the head of Loch Riddon, Argyll and Bute, is within the Ruel Estuary SSSI, south-east of Ormidale (figure 3.24). The sampled area is on the west bank of the River Ruel (55°58'47.53" N, 5°11'36.64" W). The marsh surface is a plateau with an irregular cliffed edge of approximately 45 cm above the flats. The maximum tidal range at Largs (SE of Loch Riddon) is 3.92 m (Tide-forecast, 2016). The underlying geology is formed of the Beinn Bheula Schist Formation (gritty psammite and pelite), a metamorphic bedrock which is covered by unlithified river terrace deposits (clay, silt, sand, gravel) as well as marine beach sediments (silt, sand, gravel) (British Geological Survey, 1832). No distinct plant vertical zonation was visible but the short sheep-grazed surface was dominated by *Puccinellia maritima* with *Glaux maritima* and *Juncus gerardii* had occasional ungrazed patches of taller vegetation predominantly *Agrostis stolonifera* and *Armeria maritima*. No pioneer zone species were present (figure 3.25). Surface samples from higher and lower ungrazed marsh and from the grazed marsh were collected together with one from the mudflat. Two sediment cores, of 60 (c I) and 70 cm length (c II) were collected from the saltmarsh and one with a depth of 30 cm (c III) from the mudflat.

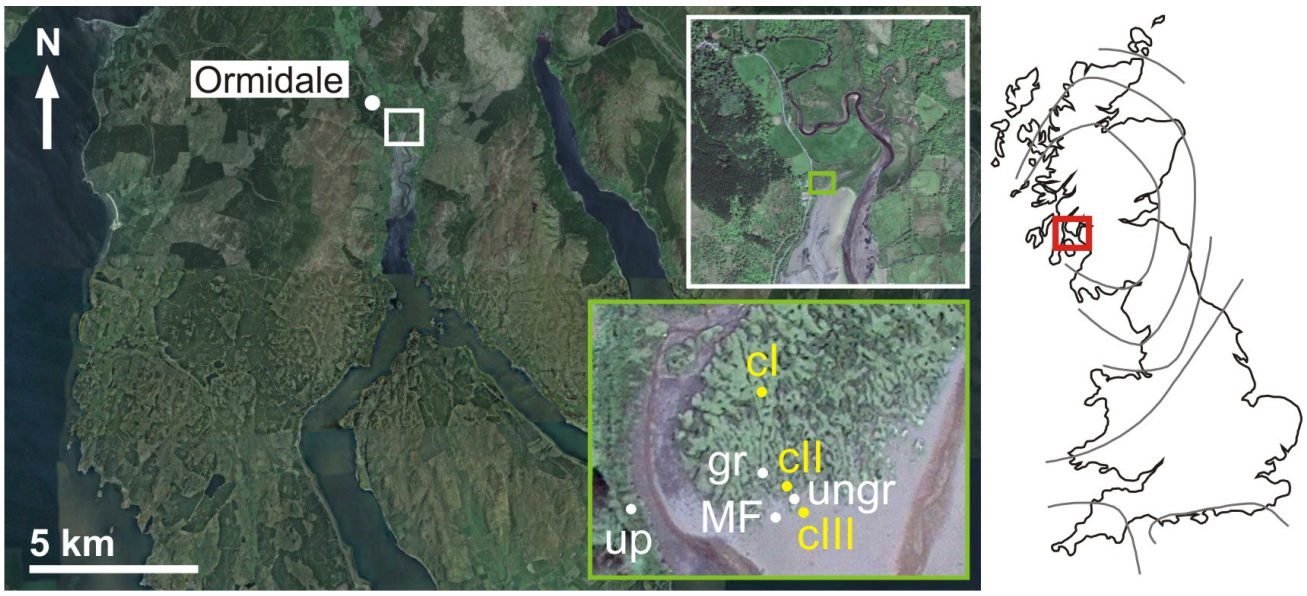


Figure 3.24.: Left: An aerial photograph (modified Google Earth) showing the location of Ormidale with the Loch Riddon saltmarsh in the white box. The green box shows a magnified image of the marsh with its surface (white) and sediment cores (yellow) locations (up = upper marsh, gr = grazed surface, ungr = ungrazed surface, MF = mudflat, c I = core I, c II = core II, c III = core III). For the samples exact location see table C.10. Right: Location of the Loch Riddon study site (red box) in the UK.

(a) Saltmarsh (b) Marsh surface (c) Marsh edge

Figure 3.25.: Photos showing the Loch Riddon saltmarsh with its typical grazed vegetation by low tide (a) Saltmarsh: sheep grazed head-loch marsh with the discharging river Ruel (top right) and the bare sandflat in front (b) Marsh surface: parallel creeks dissecting the marsh with patches of ungrazed areas (*Agrostis stolonifera*), and (c) Marsh edge: in front of marsh exists only bare mud (sandy), the edges of the marsh were also covered by algae (light green).

3.2.12. Kyleakin (KY)

This small saltmarsh is at the head of a small tidal inlet An t-Ob at Kyleakin (figure 3.26), on the south-eastern coast of the Isle of Skye in north-west Scotland (57°16'17.67" N, 5°44'25.76" W). The saltmarsh forms a plateau with salt pans and dissected by creeks terminating in a cliff 30 cm high. The maximum tidal range at Portree (NW

of Kyleakin) is 5.7 m (Tide-forecast, 2016). The underlying geology consists of the Applecross Formation (sandstone), the sedimentary bedrock is covered with alluvium deposits (clay, silt, sand, gravel) (British Geological Survey, 1832). The higher marsh vegetation is dominated by *Elytrigia repens* and *Festuca rubra*, and the lower marsh by *Puccinellia maritima*, *Aster tripolium* and *Plantago maritima*. *Glaux maritima* appears throughout the marsh. No pioneer zone vegetation was present (figure 3.27). Four surface samples were collected, from the high and low marsh, a salt pan and the mudflat. Two sediment cores 50 cm (c I) and 57 cm deep (c II) were extracted from the high and high-mid marsh zone.

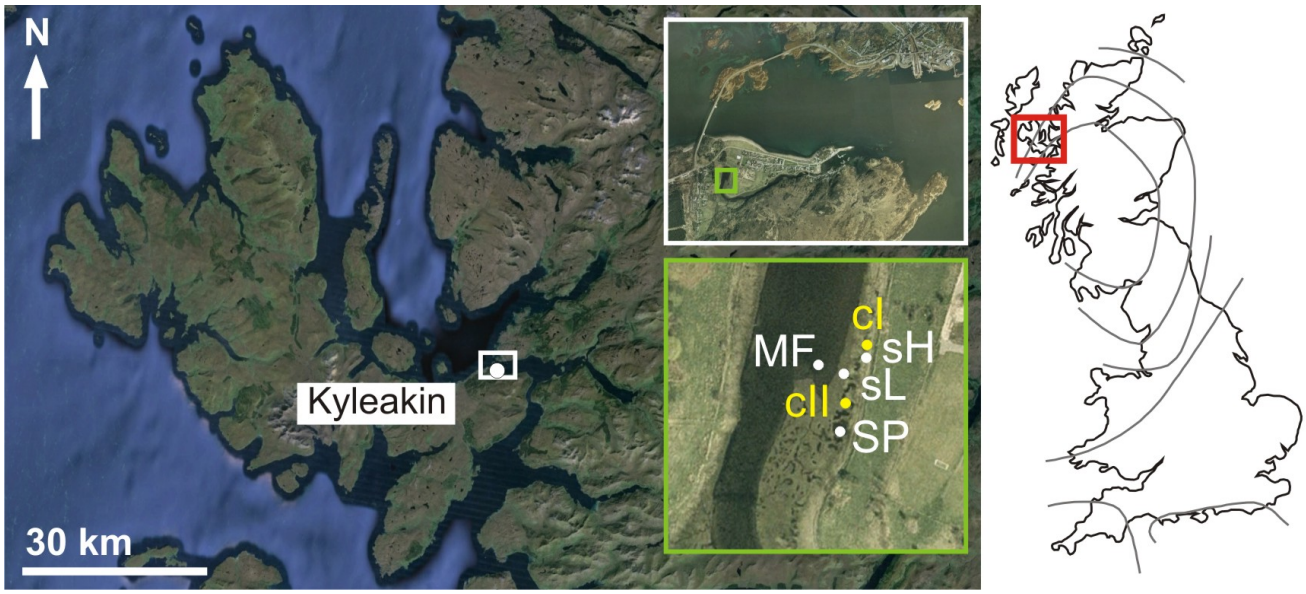


Figure 3.26.: Left: The aerial photograph (modified Google Earth) of the Isle of Skye with the location of Kyleakin. Here, a magnified image of the saltmarsh is shown in the green box. Within, the surface samples (white) and two sediment cores (yellow) are indicated (sH = surface high, sL = surface low, MF = mudflat, SP = salt pan, c(c I)I = core I, c(c I)II = core II). For the samples exact location see table C.11. Right: Location of the Kyleakin study site (red box) in the UK.

(a) Saltmarsh

(b) Marsh vegetation with salt pans

(c) Marsh edge with cliff

Figure 3.27.: Photos showing the Kyleakin head-loch saltmarsh with its typical vegetation and cliff by low tide (a) Saltmarsh: (b) Marsh vegetation with salt pans: the pans are water filled and the surface is covered by *Puccinellia*, *Aster* and *Plantago*, and (c) Marsh edge with cliff: accumulated waste (plastic) at the cliff with patches of vegetation in front.

3.2.13. Loch Ainort (LA)

This saltmarsh (figure 3.28) lies at the head of Loch Ainort on the east coast of the Isle of Skye (57°16'11.27" N, 6°04'58.36" W). The saltmarsh forms a plateau with a cliff 10 to 40 cm high. The maximum tidal range at Portree (NW of Kyleakin) is 5.7 m (Tide-forecast, 2016). The sediment of the creeks and salt pans is mainly gravel and boulders originating from the igneous bedrock which consists of granite and granophyr from the Loch Ainort Granite (western Red Hills Centre: Phase 6). It is covered by marine (clay, silt) and raised marine deposits (clay, silt, sand) (British Geological Survey, 1832). The saltmarsh vegetation shows a patchy distribution rather than a vertical zonation and is grazed by sheep. The common plants were: *Puccinellia maritima*, *Plantago maritima*, *Juncus ambiguus*, *Glaux maritima*, *Festuca rubra* and *Armeria maritima*, the last two were the most abundant. *Calluna vulgaris* (common heather) mixes with the highest marsh vegetation (figure 3.29). One surface sample was collected from the outer marsh plateau together with a sediment core of 35 cm depth (c I). Another sediment core is 89 cm deep (c II) and taken from the heather immediately above the saltmarsh.

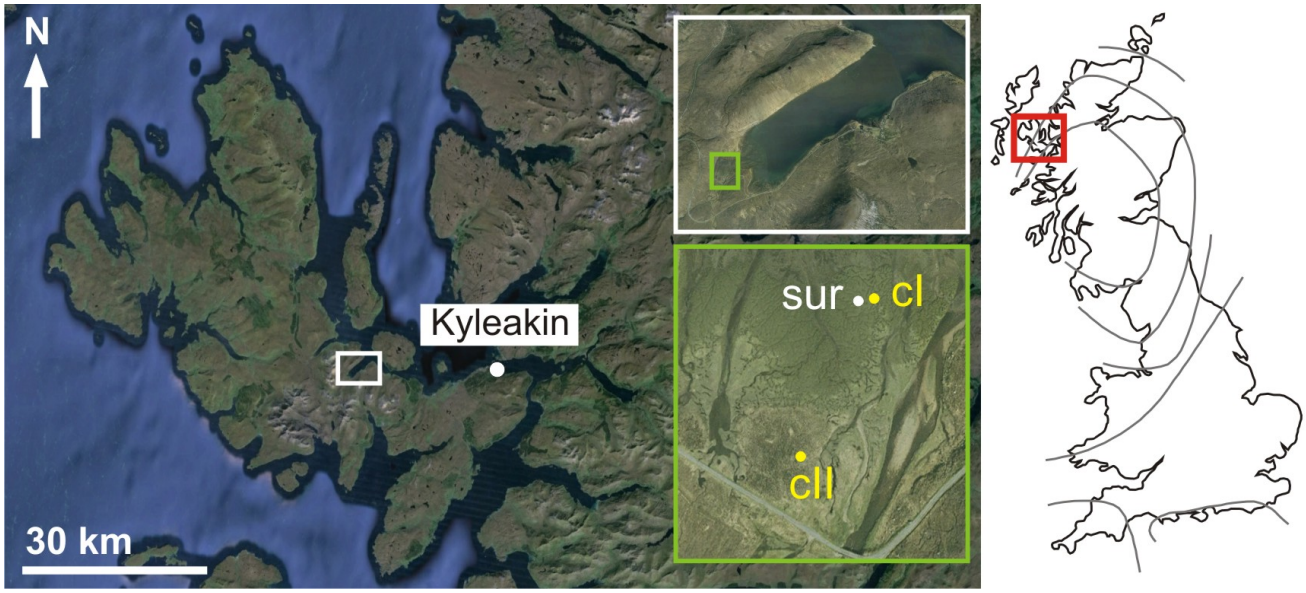


Figure 3.28.: Left: The aerial photograph (modified Google Earth) of the Isle of Skye with the location of Kyleakin. The Loch Ainort saltmarsh lies west, indicated by the white box. The green box shows a magnified image of the marsh with the sampling spots. The surface sample (white sur) and both sediment cores (yellow c I and c II) are indicated. For the samples exact location see table C.12. Right: Location of the Loch Ainort study site (red box) in the UK.

(a) Saltmarsh (b) Marsh vegetation (c) Mid-low marsh

Figure 3.29.: Photos showing the Loch Ainort head-loch saltmarsh with its typical vegetation (a) Saltmarsh: an overview of the marsh by mid tide (b) Marsh vegetation: in front of the photo, heather is visible which was growing at the highest elevation, whereas the marsh is covered with a mix of *Puccinellia*, *Plantago*, *Juncus*, *Glaux*, *Festuca* and *Armeria*, but no zonation is visible, and (c) Mid-low marsh: the marsh (by low tide) forms a small cliff and the gravel in front of is covered in patches.

3.2.14. Loch Sligachan (LS)

This sampled saltmarsh is at the head of Loch Sligachan (figure 3.30) also on the east coast of the Isle of Skye (57°17'49.10"N, 6°09'42.09"W). The marsh forms a plateau terminating in a cliff 40 cm hight. The vegetated surface is dissected by creeks and salt pans in which the sediment is covered by gravel and boulders. The maximum tidal range at Portree (NW of Kyleakin) is 5.7 m (Tide-forecast, 2016). The igneous bedrock consists of

Figure 3.30.: Left: An aerial photograph (modified Google Earth) of the Isle of Skye with the location of Kyleakin. West of it, white box, lies Loch Sligachan, where the green box shows a magnified image of the saltmarsh. On it, the sampling sport of the sediment core (yellow C) is indicated. For its exact location see table C.13. Right: Location of the Loch Sligachan study site (red box) in the UK.

the Skye Lava Group (basalt and microgabbro) which is covered by marine (clay, silt) and raised marine deposits (clay, silt, sand) (British Geological Survey, 1832). The saltmarsh vegetation is grazed by sheep and the com-

mon species were: *Festuca rubra*, *Glaux maritima*, and *Armeria maritima* with the algae *Fucus cottonii* attached to some of the larger stones (figure 3.31). One sediment core with 42 cm depth was collected from the higher elevation of the marsh.

Figure 3.31.: Photo of the Loch Sligachan head-loch saltmarsh by high tide. The surface shows shortened vegetation due to sheep grazing, no plant zonation is visible.

3.2.15. Holkham (NNC 17) and Stiffkey (Hol and SK)

Samples were taken from the sediment core (NNC 17) which was provided by the BGS and collected (52°47'56.47"N, 0°48'40.47"E) north of Holkham in north Norfolk in 1997 (NERC, Land-Ocean Evolution Perspective Study (LOEPS) of the Land-Ocean Interaction Study (LOIS)). The core was a part of a transect of three cores from Holkham to Holkham Bay and overlapping an earlier transect (Funnell & Pearson, 1989). Three 2 cm thick sediment samples were extracted from each 1 m length of the 9 m deep core. The core was taken in a grazing meadow which is a reclaimed saltmarsh land following construction of an embankment from 1639 onwards (figure 3.32). The sampling site is a back-barrier saltmarsh and lies behind a sandy barrier (Boomer, 1998). The underlying geology consists of the Lewes Nodular Chalk Formation, Seaford Chalk Formation, Newhaven Chalk Formation and Culver Chalk Formation. This sedimentary bedrock is covered by tidal flat deposits (clay, silt) which were formed behind a sandbank (British Geological Survey, 1832). The tidal range at the North Norfolk coast is 7 m (Horne & Boomer, 2000). As surface samples were not available at Holkham these were extracted from the open coast saltmarsh at Stiffkey, 10 km to the east. Here samples from the high (HM), mid (MM) and low marsh (LM) zones were collected.

Figure 3.32.: Left: An aerial photograph (modified Google Earth) of the north Norfolk coast with the location of Holkham. The white and green box shows an magnified image of the saltmarsh with the location of the sediment core NNC 17 (yellow) in the latter one. Right: Location of the Holkham study site (red box) in the UK.

4. Extraction Experiment - Results and Discussion

This chapter presents the data of 60 surface sub-samples with discussion of the extraction experiment described in chapter 2.3. This experiment was conducted because of the effect of plant remains on sieved and dried saltmarsh surface samples. This led Ostracoda and Foraminifera to be clumped together within the organic material and therefore, could only be picked out by adding water. As a result, two problems occurred: the shells had often been broken in the process of removing them and it would have taken more time to picking. Therefore, different extraction methods were studied, and it was concluded to try a floating and decanting method for Ostracoda only. This was done since most of the studied methods would be effective for Foraminifera, and this method was the easiest one to separate them from other particles. However, since this study included also Ostracoda, it was necessary to prove if it would work for all used micro-organisms.

4.1. Results

Since the extraction experiment started after the beginning of the seasonal study, the 125 µm sieved residues that were used here are ranging from June 2012 to April 2013. This bimonthly sampling included 6 month with five samples each: two *Atriplex* samples (A 1 and A 2), two creek rim samples (CR 1 and CR 2) as well as one algae sample which is growing on *Atriplex* (AA). Then, each was split into two sub-samples due to the separation of the plant (I) and sediment (II) part in the context of the experiment (chapter 2.3), leading to a total sub-sample number of 60. The high marsh samples were omitted due to the absence of Ostracoda.

From these, a total of 812 Ostracoda specimens were picked (table 4.1) with 273 individuals from the plant (I) and 539 specimens from the sediment sub-samples (II). The proportion is 34% (I) to 66% (II) for all samples. Each month 76 (April 2013) up to 171 (December 2012) Ostracoda were recovered with an average of 135 specimens per month. For each sample (AA, A 1, A 2, CR 1 and CR 2) the combined absolute abundance of all months show always a higher quantity in sub-sample II than I. Here, for AA the proportion is 31% to 69% between I and II, for A 1 24% to 76%, for A 2 35% to 65%, for CR 1 48% to 52% and for CR 2 34% to 66%.

Figure 4.1 represents the distribution of Ostracoda picked from all 30 samples. From each of those, the total number of specimens as well as the percentage of sub-sample I and II is shown. For June 2012, the AA sample

Table 4.1.: The table represents the total number of picked Ostracoda specimens from the *Atriplex* algae (AA), *Atriplex* (A 1, A 2) and creek rim (CR 1, CR 2) samples for the month June 2012 to April 2013. Also, the absolute abundance of specimens is shown for each month and sample. Each one of them was split into a plant (I) and a sediment (II) part for the extraction experiment. A total of 812 Ostracoda specimen were picked, ranging from 76 to 171 specimens per month.

	AA		A 1		A 2		CR 1		CR 2		total
	I	II	I	II	I	II	I	II	I	II	
June 2012	0	0	2	48	18	69	3	2	0	1	143
August 2012	4	9	3	21	30	46	12	6	7	15	153
October 2012	5	14	10	16	41	42	11	15	2	13	169
December 2012	3	8	13	10	31	56	12	16	11	11	171
February 2013	2	5	10	20	13	37	0	1	4	8	100
April 2013	5	7	2	11	15	25	1	3	3	4	76
total	19	43	40	126	148	275	39	43	27	52	812

contains no Ostracoda. Samples A 1, A 2 and CR 2 show more specimens in sub-sample II than I. However, for sample CR 1 this distribution is reversed. The *Atriplex* samples (A 2) show the highest abundance of Ostracoda out of all. The sample with the highest abundance of specimens (83 for A 2), shows almost a 50:50 ratio between I and II. Whereas, sample CR 2 contains the lowest Ostracoda abundance of 15 individuals. For December 2012, the samples AA, A2 and CR 2 contain more Ostracoda in sub-sample II than I. This distribution is reversed for the samples A1 and CR 2. A2 again is the sample with the highest abundance of Ostracoda, a total of 87 individuals. February 2013 shows a similar Ostracoda distribution as October 2012. Here, in all samples more specimens were collected from sub-sample II than I. The sample A 2 contains the highest abundance with 50 Ostracoda, whereas CR 1 shows the lowest with only one individual. April 2013 again shows for all samples that more Ostracoda were found in sub-sample II than I. Sample A 2 contains the highest Ostracoda abundance of 40. The least amount of specimens was found in sample CR 1 with 4 individuals. In summary, sample A 2 for all six months always contains the highest abundance of Ostracoda, ranging from 40 to 87 individuals. The lowest abundance of Ostracoda is split between AA, CR 1 and CR 2 for all months, ranging from 0 to 15 specimens. Also, three out of six months show that all their samples contain more Ostracoda in sub-sample II than I. For the remaining three months, up to two samples show a reversed distribution between sub-sample I and II: The CR 1 samples for June and August 2012 as well as two samples, CR 2 and A1 for December 2012.

The sample volume (table 4.2) taken per month was the same, except for the *Atriplex* algae, since the algae was collected per hand (about half of a one litre a plastic bag). From the *Atriplex* (mid marsh) 30 cm^3 and from creek rim (low marsh) 10 cm^3 was collected (chapter 2.1.2). A total of 27.872 g sediment was sorted through for Ostracoda. The dried residue in I and II per sample and month shows some variations. Per month, this variation

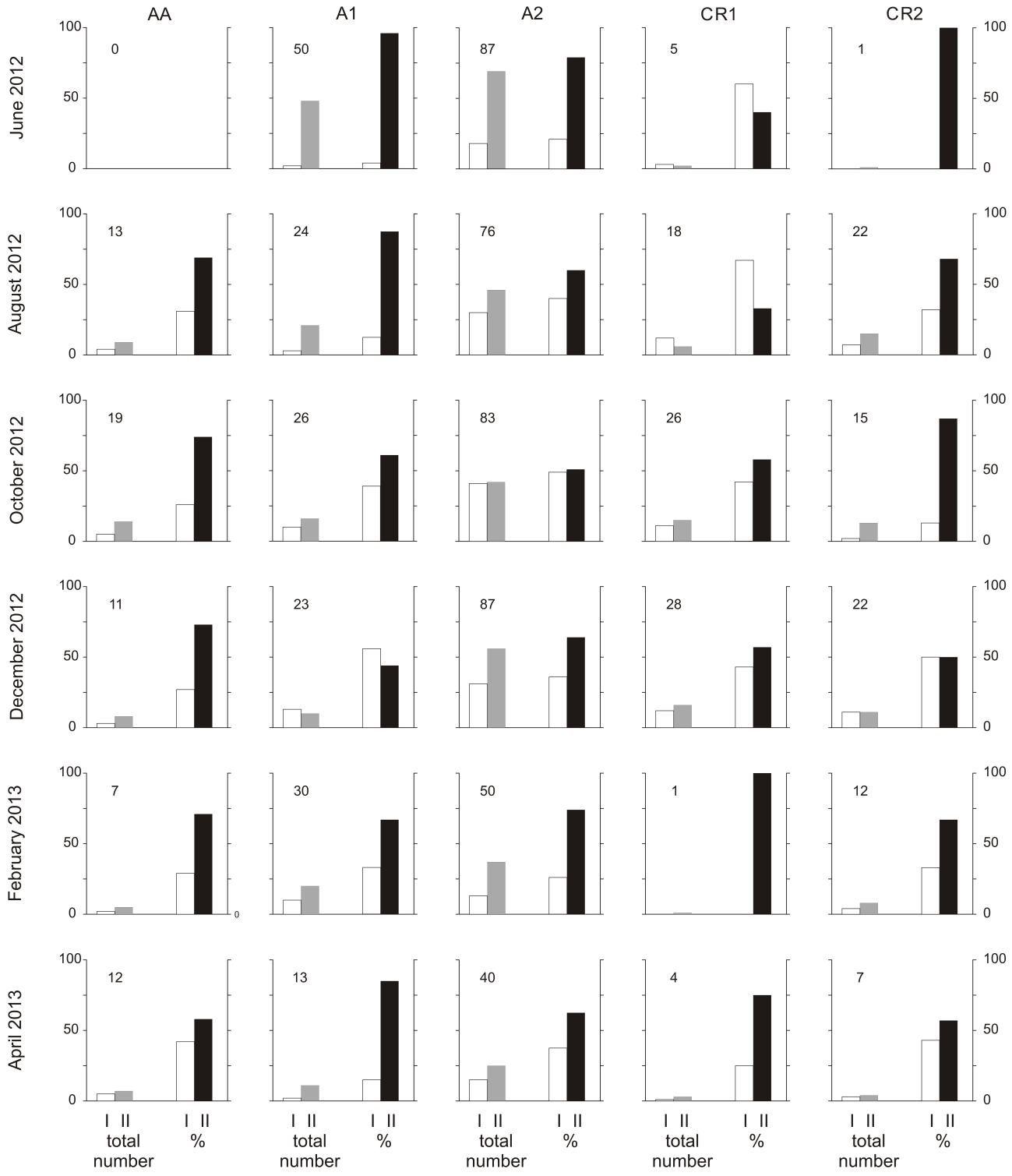


Figure 4.1.: The table represents six months (from June 2012 to April 2013) with five samples each (AA = *Atriplex* algae, two *Atriplex* = A 1 and A 2, two creek rim = CR 1 and CR 2), that were split into plant (I) and sediment part (II). Total number of Ostracoda specimens are shown on the top left of each sample. Also shown in total specimen numbers (white and grey) as well as percentage % (white and black) Ostracoda abundance of I and II sub-samples. The total number of specimens ranges from 0 to 87 individuals per sample, where the percentages of sub-sample II predominate over I with few exceptions.

Table 4.2.: Table showing the weight of dried residue in grams that was sorted through for each sample and split into a plant (I) and sediment (II) part each. One sample of AA (*Atriplex* algae) and two samples each of A (*Atriplex*) and CR (creek rim) were analysed from June 2012 to April 2013 for Ostracoda. The average weight per month is 4.638 g with a total of 27.872 g sediment sorted through.

	AA		A1		A2		CR1		CR2		total
	I	II	I	II	I	II	I	II	I	II	
June 2012	0.334	0.359	0.415	0.978	0.481	0.909	0.094	0.207	0.081	0.055	3.913
August 2012	0.765	0.518	0.731	1.547	0.303	0.897	0.135	0.303	0.149	0.259	5.607
October 2012	0.327	0.638	0.606	1.016	0.443	0,490	0.054	0.251	0.091	0.144	4.060
December 2012	1.805	0.662	0.483	0.496	0.219	0.409	0.098	0.211	0.051	0.131	4.565
February 2013	0.533	0.937	0.515	1.318	0.565	0.802	0.033	0.134	0.034	0.101	4.972
April 2013	1.257	1.231	0.335	0.669	0.367	0.568	0.052	0.131	0.071	0.029	4.710
total	5.021	4.305	3.085	6.024	2.378	4.075	0.466	1.237	0.477	0.719	27.872

ranges from 3.913 g (June 2012) up to 5.607 g (August 2012) with an average of 4.638 g. Also, the combined total sediment amount of each month and sub-sample normally indicates more material in II than I, except for AA. This is because AA is a plant-rich sample where sub-sample I containing the algae (5.021 g) outweighs the trapped sediment (II) in it (4.305 g). The heaviest samples are A1 (9.109 g) and A2 (6.453 g) due to the highest sample volume. Compared, CR1 and CR2 contain each 1.703 g and 1.196 g.

The only extraction experiment conducted with Foraminifera was done with one sample (TCE 16) of the 2.5 m long sediment core from Tollesbury. Here, the sample was split into sub-samples, I (plant) and II (sediment), and Foraminifera were picked out. This was done to test if the extraction method would also work on core samples, since they still contained some plant material. The result, a total of 41 specimens were collected including one Foraminifera fragment. Sub-sample I contains 4 specimens, whereas, sub-sample II contains 37 individuals. It was not possible to experiment with more core samples due to time limitations.

4.1.1. Observations

Additionally to the data shown in chapter 4.1, observations were made when conducting the extraction experiment. First, the *Atriplex* algae samples contained no living Ostracoda, mainly valves, mostly juvenile, were found in the samples. Second, in all sub-samples I (plant) more juveniles and broken parts of Ostracoda were collected, in contrast to the carapaces found in II (sediment), and even when sub-sample I contained carapaces, they were smaller than 100 µm. The bigger specimens were always collected from the sediment part II. This was also observed with Foraminifera, where the ones in the plant remains were always smaller than the mesh size of the 125 µm sieve. Third, the material weight per sub-sample showed variations, as mentioned above and shown in

table 4.2. However, for all samples, when picking through sub-samples, it was counted how often the material was spilled on a picking tray.

4.2. Discussion

Although previous extraction methods were focused on Foraminifera (Cushman, 1959; Brasier, 1970; Murray, 1979; Bignot, 1985; Haslett, 2000; Schönfeld, 2012), this extraction experiment was focused on Ostracoda only, with one exception. Here, each surface sample was split into a plant (I) and sediment (II) sub-sample which was then sorted through, to determine where the Ostracoda would accumulate most. The results in chapter 4.1 show that from six months, of 30 samples that were split (60 total), most contained more Ostracoda in sub-sample II than in I. 26 samples out of 30 showed this distribution. The remaining ones contained more specimens in sub-sample I than II, with one of them empty. It could be argued that the specimen numbers per sample varies strongly, between 0 and 87 in total, and often between sub-sample I and II there would be only one individual difference. However, the observations that were made for sub-sample I lead to the conclusion, that most Ostracoda, estimated 90% of them, had a size below 100 µm, even if the mesh size of the sieve was 125 µm. This could be explained by the plant remains not only agglutinating the sieved residue together. They also caught and trapped smaller sized specimens than the 125 µm sieve would allow, which would have been normally lost due to the sieving. Furthermore, because of their smaller size, the sub-sample I mostly contained juveniles of both micro-organisms or only fragments of them. This was also true for the one core sample (TCE 16) for Foraminifera.

Another issue would be the sample weight, about which one could argue that sub-sample II contained more material due to its higher weight and therefore had more Ostracoda in it. But since sediment is heavier than plant remains, this would lead to the conclusion that sub-sample I should be lighter than II. To compare the amount that was sorted through between the sub-samples, the picking tray was used. Here, how many times it would be used to sprinkle the material on the plate per sub-sample was counted, which could then be compared. This seemed unusual, since the sediment part is heavier than the plant part, leading to the conclusion that more material was in sub-sample II. Therefore, it could be assumed that the picking tray would be needed more often for this sample, as compared to the lighter plant material. The solution to this contradiction is simple, the sediment particles are not only heavier due to higher density, but also smaller. Therefore, they would need a smaller space to be sprinkled on, in contrast to the lighter plant material. Here, the plant particles were often long filaments or leave remains that would cover a larger area. This lead to a bigger space that would be used, and consequently the picking tray was used to the same amount as sub-sample II. Furthermore, the smaller sediment particles that were trapped with the organic material also needed a bigger area to be sorted through properly, in order that no Ostracoda be overlooked.

5. Systematics

In this chapter, systematic problems, and their history, of Foraminifera and Ostracoda are summarised and discussed. From 244 samples, 8 196 Ostracoda and 58 601 Foraminifera specimens were collected and analysed. All species are listed according to their taxonomic order here. For each, a short synonymy is included with references of their first publication. Additional publications indicate taxonomic problems which are described in the following discussion. Furthermore, more recent publications are referenced in the synonymy which add new taxonomic data. Also, a brief summary of species occurrences of all study sites are given, while all details are revealed in chapter 6. Comments on any alterations between the known and found specimens are described in the discussion part. This includes new information and a formal description in case of rare species. With the help of the cited literature, the species were identified and then experts were consulted to verify the findings.

5.1. Foraminifera

A total of 58 601 specimens of Foraminifera were examined, belonging to 16 families and 18 genera. They belong to the four suborders of Textulariina, Miliolina, Allogromiina and Rotaliina (chapter 1.3.2). The classification used here is after Murray (1979), Loeblich & Tappan (1987), Murray (2003), Horton & Edwards (2006a) and Hayward et al. (2015). J. Murray and J.E. Whittaker also examined the picked species in order to discuss and verify the identifications.

The history of Foraminifera systematic began in the 17th century. Antonie van Leeuwenhoek made the first Foraminifera find and thought them to be small snails. However, its drawing was detailed enough to identify it as an *Elphidium*. The first attempt at a taxonomic order was undertaken by H.B. Brady in its monograph (1884) on the collected material from the Challenger expedition from 1873 to 1876. In it, 10 families and 29 subfamilies are described. Later, in Cushman's expanded classification (1927) 35 families appeared, which increased to 50 in Cushman's final version of 1948. Here, the wall structure of Foraminifera was established as "the primary basis for first level splitting" (Gupta, 1999). Also new was the use of Foraminifera in the petroleum exploration, where it was criticised that Cushman's classification "served the commercial purpose more than the biological one" (Gupta, 1999). In 1949, Wood discovered more optical characteristics of the calcareous hyaline genera. This made it possible for Loeblich & Tappan (1964) to establish suprafamilial taxonomic entities with 5 orders, 17

superfamilies and 94 families. In this classification, besides wall material and chamber arrangement, additional features such as apperture and environmental adaptation (planktonic, benthonic) were used. The reason for this was to attempt to exclude parallel evolution where the test form with its chamber arrangements may have developed independently. Later modifications of Loeblich & Tappan were produced with 12 suborders in the 1987 classification which changed to 10 in 1992. The morphological features from Loeblich & Tappan (1987) are used in present classifications, but with a modified version of 16 suborders from the 1992 modification. This is similar to the classifications produced by Lee (1990) and Haynes (1981). A list of all 16 suborders is shown in Gupta (1999) table 2.2 (page 17).

In comparison, (palaeo)ecological studies started late in the middle of the 20th century by Phleger (1960). Since then, the understanding of the geological past has increased significantly. This was only possible because of Foraminifera diversity and the preservation of their tests. However, some are better preserved than others, leading to taphonomic bias regardless of the sediment age (Gupta, 1999). For a more detailed description of taphonomic problems and issues influenced by abiotic and biotic factors see chapter 2.1.1. Recently, genetic research (DNA sequencing) on Foraminifera has been conducted where species level taxonomy has been studied. First findings show surprising results, like the high morphological variability of *Elphidium* tests (Evans et al., 2012). Its taxonomy was confusing from the beginning with hardly any clear species boundaries between the 60 morphospecies. The problem is that morphological variants were used to distinguish distinct species (Evans et al., 2012), and not only on *Elphidium*. Therefore, genetic research helps to find true diversity and tries to prevent taxonomic bias. Another case represents the taxon *Ammonia* with similar variability problems (Murray, 1979). Also, genetically close relationships between *Elphidium* and *Haynensina* show problems due to their similar morphological features. And beside these issues, of finding true diversity and species boundaries, a unified classification is missing. Meaning, that for identifying species several references have to be used. The most common references are Loeblich & Tappan 1964 or 1978, Haynes 1981 and Sen Gupta 1994 (Radl, 2012). And as described above, each differs in their families and genera numbers. Even though, they all contain the same suborder number of 16.

Taking all the systematic problems as described above into consideration, the following list of Foraminifera attempts to order them regarding to the newest systematic information. Therefore, a modified version of Loeblich & Tappan (1987) with its 16 suborders was used, in combination with recent literature. For a list about the absolute abundance of all Foraminifera species per sample, see appendix D. Supplementary, images of the most common and rare species are shown in Plate 1 to 5.

Order: FORAMINIFERIDA Eichwald, 1830

Suborder: TEXTULARIINA Delage & Hérouard, 1896

Superfamily: TEXTULARIACEA Ehrenberg, 1838

Family: LITUOLIDAE de Blainville, 1827

Subfamily: AMMOMARGINULININAE Podobina, 1978

Genus: *Ammobaculites* Cushman, 1910

5.1.1. *Ammobaculites* sp.

Plate 1, fig. 1

Occurrence: Representatives of this genus were found and collected only from the northern sampling area on the Isle of Wight.

Discussion: Since the focus of the study on the Isle of Wight was on Ostracoda, no Foraminifera were counted. Furthermore, only observations were made about the Foraminiferal assemblage for this saltmarsh, and therefore not all specimens were identified on the species level. However, no more than one species of *Ammobaculites* was found. Also, it preferred the lower marsh area, where it was found most abundant.

Family: EGGERELLIDAE Cushman, 1937

Subfamily: EGGERELLINAE Cushman, 1937

Genus: *Eggerella* Cushman, 1935

5.1.2. *Eggerella scaber* (Williamson, 1858)

Plate 1, fig. 2

1973 *Eggerelloides scabrum* [sic] (Williamson); Haynes: 44, pl.2, figs.7, 8; pl.19, figs.10, 11; textfigs.8.1-4.

1979 *Eggerella scaber* (Williamson); Murray: 26, fig.6A-c.

2006 *Eggerella scaber* (Williamson); Horton & Edwards: 66, pl.1, fig.2a.

Occurrence: The only study site were this species was found was the northern sampling area on the Isle of Wight.

Discussion: No counts were made, only observations (see *Ammobaculites* sp.). Most specimens of *Eggerella scaber* were found in the low to mid marsh area.

Family: TROCHAMMINIDAE Schwager, 1877

Subfamily: JADAMMININAE Saidova, 1981

Genus: *Jadammina* Bartenstein and Brand, 1938

5.1.3. *Jadammina macrescens* (Brady, 1870)

Plate 1, fig. 3-9

1938 *Jadammina polystoma* Bartenstein & Brand: 381, text-figs.1-3.

1988 *Jadammina macrescens* (Brady); Brönnimann & Whittaker: 36, pl.2, fig.3.

1979 *Jadammina macrescens* (Brady); Murray: 28, fig.6K-M.

2006 *Jadammina macrescens* (Brady); Horton & Edwards: 68, pl.1, fig.4a-d.

2011 *Jadammina macrescens* (Brady); Callard et al.: 125, pl.1, fig.4-5.

Occurrence: This species was found in all analysed study sites. At Tollesbury, it appeared in al surface samples and was most abundant in the mid (*Atriplex*) to high marsh samples (*Elytrigia* and *Puccinellia*). Even though it was also found at lower elevations, more tests were broken or damaged. It also was found in all samples of the sediment cores from Tollesbury, except of sample TCE 3 of the *Elytrigia* core. At Two Tree Island, it was collected from all surface, especially abundant in the mid-high marsh sample (P 6). Also, it was found in a few core samples, most abundant in the first metre. The species was also found in all surface samples in the northern and southern sampling area on the Isle of Wight. At Gann, *Jadammina macrescens* appeared to be the dominating Foraminifera in the mid marsh (A 1). In all other surface sample it was found as well, and also in all core samples, where it was the dominant species. At Loch Riddon, this species also appeared in all samples, surface and core (except cI 1 sample), with its highest abundance found at the ungrazed mid marsh and mid marsh sediment core (cII 1 to 7). At Kyleakin, it shows the same distribution as at the previous study site, highest abundance at mid marsh (cI sur) and both mid marsh sediment cores. Only in the salt pan no *J. macrescens* was found. At Loch Ainort, it appears in all samples were Foraminifera were found with its highest abundance on the surface, where the sample was collected from mid marsh. In the sediment core from Loch Sligachan, all samples contained *J. macrescens*. In Norfolk, at Stiffkey, it was collected from all surface samples as well, but was found in not all sediment core samples from Holkham (NNC 17).

Discussion: *Jadammina macrescens* is a true brackish-water species (Horne & Boomer, 2000) and therefore, was found at all sites. Mostly between high and mid marsh it reached its highest abundance. The tests varied slightly between the sites. AT Tollesbury, they were mostly smaller and depressed when dried. Whereas, from the Isle of Wight, they were bigger and did not deflate as easily. At the northern sampling area, this species was found with a *feeding tube* as it was once also described from *Trochammina inflata* (Horton & Edwards, 2006a). This was however, not found at any other sites. The smallest tests were collected from the Isle of Skye, where it appeared also strongly deformed at Loch Ainort and Loch Sligachan. Here, the sediment particle which it normally uses to build its test also were more coarse, possible due to the available grain size of sediment at this location. This was also observed at Loch Riddon.

Subfamily: TROCHAMMININAE Schwager, 1877

Genus: *Trochamminoides* Cushman, 1910

5.1.4. *Trochammina inflata* (Montagu, 1808)

Plate 2, fig. 1-8

1988 *Trochammina inflata* (Montagu); Brönnimann & Whittaker: 34, pl.1, fig.1.

1979 *Trochammina inflata* (Brady); Murray: 26, fig.6E-G.

2006 *Trochammina inflata* (Brady); Horton & Edwards: 69, pl.2, fig.8a-d.

2008 *Trochammina inflata* (Brady); Berkeley et al.: 243, pl.1, fig.7.

2011 *Trochammina inflata* (Brady); Callard et al.: 125, pl.1, fig.1-3.

Occurrence: This species was collected from all analysed study sites. At Tollesbury, it was found to be most abundant at high (*Elytrigia*) and high-mid marsh (*Puccinellia* and *Atriplex*), but was also found at lower elevations, same as *Jadammina macrescens*. From there, more broken tests were collected. Further, it was found in all sediment core samples. At Two Tree Island, mid and low marsh surface samples contained *T. inflata*. In the sediment core from this site, it was most abundant in the first metre, then mostly broken tests were collected. From high to mid marsh, this species was also identified at the northern and southern sampling site on the Isle of Wight. At Gann, it was found in all surface and core samples, with its highest abundance at high marsh. At Loch Riddon, it was found at the mid marsh (grazed and ungrazed) and in nearly all sediment core samples. At Kyleakin, this species showed its highest abundance at low marsh (LM 2) and the mudflat (MF). It was collected

from all sediment core samples as well. At Loch Ainort, *T. inflata* was found in only one sediment core sample (cII 9) of the high marsh core (cII) in the deepest sample. At Loch Sligachan however, no specimens were found. In Norfolk, at Stiffkey, it was collected only from the high (HM 1) and mid marsh (MM 1). In the sediment core from Holkham (NNC 17), it appeared only sporadical.

Discussion: *Trochammina inflata* is a true brackish-water species (Horne & Boomer, 2000) and was found at all saltmarsh sites. It is most abundant at high marsh. The test does not change as much as *Jadammina macrescens* between sites, only in the northern areas the agglutinated sediment seems to be coarser, possible due to the available grain size of sediment at this location. From the northern sampling area at the Isle of Wight, it was also found with an elongated *feeding tube*, as was described by Horton & Edwards (2006) from the Cowpen Marsh, North Sea coast, NE England. Furthermore, it was observed, especially at Tollesbury, that instead of a dimorphism, a possible trimorphism might exist as described by Lehmann et al. (2006).

Superfamily: LITUOLACEA de Blainville, 1827

Family: HAPLOPHRAGMOIDIDAE Maync, 1952

Genus: *Haplophragmoides* Cushman, 1910

5.1.5. *Haplophragmoides wilberti* Andersen, 1953

Plate 3, fig. 1-4

1979 *Haplophragmoides wilberti* Andersen; Murray: 24, fig.5G-H.
2008 *Haplophragmoides wilberti* Andersen; Berkeley et al.: 243, pl.1, fig.1.
2011 *Haplophragmoides wilberti* Andersen; Callard et al.: 125, pl.1, fig.6-7.
2014 *Haplophragmoides wilberti* Andersen; Culver et al.: 5, pl.2, fig.9.

Occurrence: *Haplophragmoides wilberti* was found at half of the analysed saltmarsh sites. On the Isle of Wight, it was observed at the northern sampling area. Here, it showed a distribution which did not seem to have a preferred marsh zone, or it was not observed. At Loch Riddon, this species had its highest abundance at the high marsh, but a few specimens were also found in the other surface samples. It appears also in all sediment cores, with its highest numbers in the hihg marsh core, top sample (cI 1). At Kyleakin, *H. wilberti* also appeared only at high marsh and the topmost samples of the high-mid marsh sediment core (cI). At Loch Ainort and also possible Loch Sliagachan, a few

very small and deformed specimens of this species could exist there as well. The problem was the grade of deformation and the size made it impossible to distinguish it from *Jadammina macrescens*.

Discussion: Besides the above mentioned identification problem due to a similar tests structure with *J. macrescens*, it could easily identified as *Haplophragmoides wilberti* at the other locations. Test variations were observed between the study sites. On the Isle of Wight it had a smooth, silvery surface and less inflated chambers. At Loch Riddon, the texture was coarser, the test more brownish and the chambers rounder. At Kyleakin, the appearance resembled the one at the Isle of Wight specimens. However, the sediment particles were a bit coarser due to the present geology. At Loch Ainort and Loch Sligachan, if the specimens truly are *H. wilberti*, they would be more like the ones found at Loch Riddon, coarser and brownish.

Superfamily: RZEHAKINACEA Cushman, 1933

Family: RZEHAKINIDAE Cushman, 1933

Genus: *Miliammina* Heron-Allen and Earland, 1930

5.1.6. *Miliammina fusca* (Brady, 1870)

Plate 3, fig. 5-9

1971 *Miliammina fusca* Brady; Murray: 21, pl.3, figs.1-6.

1979 *Miliammina fusca* (Brady); Murray: 23, fig.5D-F.

2006 *Miliammina fusca* (Brady); Horton & Edwards: 68, pl.1, fg.5a-b.

2008 *Miliammina fusca* (Brady); Berkeley et al.: 243, pl.1, fig.4.

2011 *Miliammina fusca* (Brady); Callard et al.: 125, pl.1, fig.10.

2014 *Miliammina fusca* (Brady); Culver et al.: 5, pl.2, fig.5.

Occurrence: *Miliammina fusca* was found in nearly all analysed study sites, except for the Norfolk locations. At Tollesbury, this species was found in very low numbers at high (E 9) to high-mid marsh (P 3). It showed the highest abundance in the salt pans at the highest elevation (SP 1). In other samples, including the sediment cores, it only was collected sporadically. At Two Tree Island, it was found in only two samples, the high-mid marsh (P 6) surface sample and in the first metre of the sediment core (sample TCP 4) in low numbers. It was also observed from the Isle of Wight, north and south, also with few specimens only. At Gann, the highest abundance was counted at mid marsh (A 1), but it was also collected from other surface samples. In the mid marsh sediment core, most *M.*

fusca were found among all three cores, even though all contained it. At Loch Riddon, this species was found in all surface samples as well as all three sediment core samples. Its highest abundance was observed in the mid marsh (grazed and ungrazed) as well as mid marsh sediment core. At Kyleakin, also appeared in all samples, surface and core, with its highest numbers collected from the high-mid marsh core (cI). At Loch Ainort, it was found in the only surface sample and also the bottom most samples of the high marsh core. At Loch Sligachan, it was the only other species encountered besides *Jadammina macrescens*.

Discussion: At other saltmarshes, it was observed that *Miliammina fusca* often appeared with few specimens only. This is true for the southern study sites, not the northern ones. At all sites, but especially where it was found in higher numbers, this species also shows a variation of its test. The surface of the smaller asexually agamont seems to be smooth, using finer sediment particles and appears to be light brown on the outer side to silvery grey in the middle. Instead the sexually produced gamont, which is bigger in size, always consists of coarser sediment and is normally grey to brownish in appearance.

Superfamily: HORMOSINACEA Haeckel, 1894

Family: HORMOSINIDAE Haeckel, 1894

Subfamily: REOPHACINAE Cushman, 1910

Genus: *Reophax* de Montfort, 1808

5.1.7. *Reophax moniliformis* Siddall, 1886

Plate 4, fig. 1-3

1886 *Reophax moniliforme* [sic] Siddall: 54, pl.1, fig.2.

1973 *Reophax moniliforme* [sic] Siddall; Haynes: 24, pl.3, fig.17; pl.6, fig.8.

1979 *Reophax moniliformis* Siddall; Murray: 23, fig.5A-B.

2006 *Reophax moniliformis* Siddall; Horton & Edwards: 68, pl.1, fig.6a-c.

Occurrence: This species was found at two sites: Tollesbury and the Isle of Wight. At Tollesbury, *Reophax moniliformis* was found to live only in salt pans (samples SP 1, SP 3, SP 4, SP 8), independent of the marsh elevation. However, at the northern area of the Isle of Wight, it was also encountered at the low marsh and in the salt pans.

Discussion: Since it appeared to be restricted to live only in salt pans at Tollesbury, this species would be a perfect indicator for salt pans if found in sediment cores. This would also be possible, since no specimens were found in other samples outside of the salt pan.

Suborder: MILIOLINA Delage & Hérouard, 1896

Superfamily: CORNUSPIROIDEA Schultze, 1854

Family: CORNUSPIRIDAE Schultze, 1854

Subfamily: CORNUSPIRINAE Schultze, 1854

Genus: *Cornuspira* Schultze, 1854

5.1.8. *Cornuspira involvens* (Reuss, 1850)

Plate 4, fig. 4-5

1850 *Operculina involvens* Reuss: 370, pl.46, fig.20a-b.

1994 *Cornuspira involvens* (Reuss); Jones: 26, pl.11, fig.1-3.

2003 *Cornuspira involvens* (Reuss); Murray: 45, pl.4, fig.5.

Occurrence: *Cornuspira involvens* was found at two study sites: Tollesbury and Gann. At Tollesbury, it was found mostly in surface samples, with the highest abundance at mid marsh (*Atriplex*). A few specimens were also collected occasionally from the low marsh, but never found at higher elevations. Only one sample sediment core (TCE 2) contained one specimen. The same distribution was found at Gann, where it showed the highest numbers at mid marsh (A 1). Here, only two sediment core samples contained one specimen each (T 3/1 and T 4/1).

Superfamily: MILIOLACEA Ehrenberg, 1839

Family: HAUERINIDAE Schwager, 187

Subfamily: HAUERININAE Schwager, 1876

Genus: *Quinqueloculina* d'Orbigny, 1826

5.1.9. *Quinqueloculina oblonga* (Montagu, 1803)

Plate 4, fig. 6

1979 *Quinqueloculina oblonga* (Montagu); Murray: 34, fig.9D-F.

Occurrence: This species was found at the southern study sites, including Norfolk and Gann. At Tollesbury it appeared at low marsh with its highest abundance at the *Salicornia* zone. Specimens were also found at mid marsh, none at high marsh. In the sediment cores no *Quinqueloculina* were found. At Two Tree Island, this species was fund in low numbers from the high-mid to low marsh, as well as three sediment core samples (TCP 1, TCP 4 and TCP 13). On the Isle of Wight, specimens were collected from the northern and southern sampling area, where it seems to prefer the low marsh area. At Gann, this species has its highest abundance at mid marsh (A 1). Other surface samples, except for the high marsh, contained also a few specimens. From this site it was also found in two sediment cores, with its highest abundance in the mid marsh core (T 3). In very few numbers, this species was also collected from the Norfolk coast at Stiffkey, mainly from the mid marsh (MM 1).

Discussion: Several species of *Quinqueloculina* exist and identification was not always easy. Therefore, the found specimens were grouped as *Quinqueloculina* spp. together for consistency reasons, even though most of them could be identified as *Quinqueloculina oblonga*. It was also observed that *Quinqueloculina* preferred to live from mid to low marsh. It has its highest abundance when *Ammonia* has its lowest.

Suborder: ALLOGROMIINA Loeblich and Tappan, 1961

Family: ALLOGROMIIDAE Rhumbler, 1904

Subfamily: ALLOGROMIINAE Rhumbler, 1904

Genus: *Allogromia* Rhumbler, 1904

5.1.10. *Allogromia* sp.

Occurrence: Specimens of this genus were found at three study sites: Isle of Wight, Gann and Loch Riddon. However at only one they were counted, where it seemed to be one species. At Gann, it was found in the high marsh sample (E 1) with low numbers. Also, all three sediment cores contained few deformed specimens.

Discussion: The specimens found belong to the only soft shelled Foraminifera encountered in the saltmarshes. Due to its fragile nature, mostly fragments were collected from the Isle of Wight and Loch Riddon, therefore no counts. The test, a single chamber, consists of agglutinated sediment particles which gives it a light brownish appearance. The aperture is located at the end of a small tube like structure. Furthermore, around the test, a band like structure (organic) exists with a stripy

(dark brown and whitish) pattern. Due to the colour and the fragility of this Foraminifera, it could be easily overlooked. Therefore, the possibility exists that it could have a wider distribution. Other species were found also in British saltmarshes (Larkin & Gooday, 2004).

Suborder: ROTALIINA Delage & Hérouard, 1896
Superfamily: ASTERIGERINACEA d'Orbigny, 1839
Family: ASTERIGERINATIDAE Reiss, 1963

Genus: *Asterigerinata* Bermúdezl, 1949

5.1.11. *Asterigerinata* spp.

Occurrence: Three to four different species of *Asterigerinata* were found only in the sediment core from Two Tree Island. Therefore, they were summarised as *Asterigerinata* spp. and mentioned only for completeness.

Superfamily: ROTALOIDEA Ehrenberg, 1839
Family: ROTALIIDAE Ehrenberg, 1839
Subfamily: AMMONIINAE Saidova, 1981

Genus: *Ammonia* Brünnich, 1772

5.1.12. *Ammonia* spp.

Plate 4, fig. 9-11

Occurrence: This species has been collected from five study sites. At Tollesbury, this species seems to prefer the low marsh area (CR samples) due to its high abundance there. A few specimens were also found in both sediment cores. At Two Tree Island, *Ammonia* was most abundant at low marsh (S 6), but a few specimens could also be found at higher elevations. In nearly all sediment core samples this species was found. On the Isle of Wight, it was observed that it preferred the low marsh area as well, at both, the northern and southern sampling area. At Gann, its highest abundance was encountered at low marsh (S 1). Only a few specimens were also collected from two sediment cores. At Norfolk, only in the sediment core from Holkham (NNC 17) *Ammonia* was identified, mostly in the middle of the core.

Discussion: This species has a high variability of its test and therefore, several attempts at distinguishing different species proves to be problematic. Whittaker, during a discussion, also suggested to summarise the found specimens under the genus *Ammonia* which was done so here, as *Ammonia* spp.. It was observed that it prefers to live at low marsh and has its highest abundance when *Quinqueloculina* has its lowest. According to Murray, different Foraminifera species, like *Elphidium*, feed on different parts of their prey (diatoms). It was also observed that through the hyaline test, two different colours could be seen when alive, brown and yellow. Therefore, it is to assume that two different species among the *Ammonia* spp. exists at the studied sites.

Superfamily: PLANORBULINACEA Schwager, 1877

Family: CIBICIDIDAE Cushman, 1927

Subfamily: CIBICIDINAE Cushman, 1927

Genus: *Cibicides* de Montfort, 1808

5.1.13. *Cibicides* spp.

Occurrence: Representatives of this genus were found only in the sediment core from Two Tree Island. Here, two to three different species were found and summarised under *Cibicides* spp..

Family: ELPHIDIIDAE Galloway, 1933

Subfamily: ELPHIDIINAE Galloway, 1933

Genus: *Elphidium* de Montfort, 1808

5.1.14. *Elphidium williamsoni* Haynes, 1973

Plate 5, fig. 1

1973 *Elphidium williamsoni* Haynes: 207, pl.24, fig.7; pl.25, figs.6, 9; pl.27, figs.1-3.

1979 *Elphidium williamsoni* Haynes; Murray: 52, fig.16C-D.

2006 *Elphidium williamsoni* Haynes; Horton & Edwards: 76, pl.4, fig.20a-b.

Occurrence: This species can be found at six study sites. At Tollesbury, this species was found, besides the mid marsh, mostly at low marsh (CR samples). Hardly any specimens were collected from the sediment cores (TCE and TC). At Two Tree Island it was collected from all surface samples, and also nearly all sediment core (TCP) samples. On the Isle of Wight, it was also found most abundant at

low marsh in the northern and southern sampling area. At Gann, *Elphidium* had its highest abundance at low marsh (S 1), but could also be found at mid to high-mid marsh. Two sediment cores (T 3 and T 4) also contained it. At Loch Riddon, this species was found only on the mudflat (sample sand). In Norfolk, at Stiffkey this species was found at mid marsh (MM 1) only. The Holkham sediment core (NNC 17) contained most specimens in the middle of it.

Discussion: Different species of the genus *Elphidium* were identified. However, due to the high variability of the test, it was difficult to identify different species, since the taxonomy of it is still in progress. Therefore, specimen were summarised as *Elphidium* spp., even tough, most of them seemed to be *Elphidium williamsoni*. This could be confirmed when they were found alive, where the same green colour could be seen through the hyaline test. As mentioned above, for *Ammonia*, different species prey on different parts of their food (diatoms). Therefore, it is to assume that they all belong to the same species, which was then identified as *Elphidium williamsoni*.

Superfamily: NONIONACEA Schultze, 1854

Family: NONIONIDAE Schultze, 1854

Subfamily: NONIONINAE Schultze, 1854

Genus: *Haynesina* Banner and Culver, 1978

5.1.15. *Haynesina germanica* (Ehrenberg, 1840)

Plate 5, fig. 6-8

1840 *Nonionina germanica* Ehrenberg: 23, pl.2, figs.1a-g.

1978 *Haynesina germanica* Banner & Culver: 191, pl.4, figs.1-6; pl.5, figs.1-8; pl.6, figs.1-7; pl.7, figs.1-6; pl.8, figs.1-10; pl.9, figs.1-11, 15, 18.

1979 *Nonion germanicum* (Ehrenberg); Murray: 54, fig.17A-B.

2006 *Haynesina germanica* (Ehrenberg); Horton & Edwards: 77, pl.4, fig.21a-b.

Occurrence: This species was found at five study sites. At Tollesbury, it appears to prefer the low marsh area (CR samples), but does not occur in high numbers as other calcareous Foraminifera. Hardly any were collected in the sediment core (TCE). At Two Tree Island, *Haynesina germanica* was found in all surface samples, with a high abundance at high-mid marsh (P 6). Also, it was collected from the sediment core (TCP) from nearly all samples. Here, it occurs in especially high abundances. On the Isle of Wight it was observed that this species was found preferably at low

marsh at the northern and southern sampling area. At Gann, its highest abundance was at low marsh (S 1), but could also be found at mid marsh. Only two sediment cores (T 3 and T 4) contained this species. From Norfolk, the Holkham sediment core (NNC 17) contained *H. germanica*, especially in the middle part.

Discussion: *Haynesina germanica* is very similar in appearance as *Nonion depressulum* (Walker & Jacob, 1798). However, it was clearly as *H. germanica* identified with the help of Murray. This species is known to have a low marsh distribution (Boomer, 1998).

Superfamily: GLOBIGERINACEA Carpenter, Parker, and Jones, 1862

Family: GLOBIGERINIDAE Carpenter, Parker, and Jones, 1862

Subfamily: GLOBIGERININAE Carpenter, Parker, and Jones, 1862

Genus: *Globigerina* d'Orbigny, 1826

5.1.16. *Globigerina* spp.

Occurrence: Few specimens of the genus *Globigerina* were found at three study sites. At Tollesbury, only two specimens were found in the high marsh sediment core (TCE). They were rounded due to transportation and slightly dissolved, but could still be identified as *Globigerina*. At Two Tree Island, at high and high-mid marsh, specimen were collected from the surface. From a depth below 2 metre, a few specimens were also counted in the sediment core, but were partly broken. At Norfolk, the Holkham sediment core (NNC 17) had six specimens in one sample (R 4/1). Here, they also showed traces of dissolution.

Discussion: Most specimens were collected from sediment cores and had a partly dissolved, rounded or broken test. Therefore, they could not be clearly identified at species level and were summarised as *Globigerina* spp.. *Globigerina* is not a benthonic saltmarsh species, but a marine planktonic. It could have been washed ashore during storm events. This explains why it was found mostly in sediment cores.

Superfamily: NODOSARIACEA Ehrenberg, 1838

Family: LAGENIDAE Reuss, 1862

Genus: *Lagena* Walker and Jacob, 1798

5.1.17. *Lagena* spp.

Occurrence: Representatives of the genus *Lagena* were collected from two study sites. At Two Tree Island, only three *Lagena* spp. were found at the mid (P 6) and low marsh (S 6). The majority were collected from the sediment core, especially at two metres depth (sample TCP 28). The second site was the northern area on the Isle of Wight. Only in the low marsh samples a few were specimens found.

Discussion: Since *Lagena* is not a brackish saltmarsh species, the few collected specimens were summarised here as *Lagena* spp..

Plate 1

Fig. 1: *Ammobaculites* sp.

1: side view, 160x, Isle of Wight (IW north).

Fig. 2: *Eggerella scaber*

2: lateral view, 120x, Isle of Wight (IW north).

Fig. 3-9: *Jadammina macrescens*

3: umbilical view, 160x, Isle of Wight (IW north).

4: spiral view, 160x, Isle of Wight (IW south).

5: tilted umbilical view with feeding tube, 160x, sle of Wight (IW north).

6: spiral view, 160x, Tollesbury (T II).

7: spiral view, 190x, Two Tree Island (TTI P 6).

8: spiral view, 190x, Loch Riddon (LR grazed).

9: spiral view, 190x, Gann (G P 1).

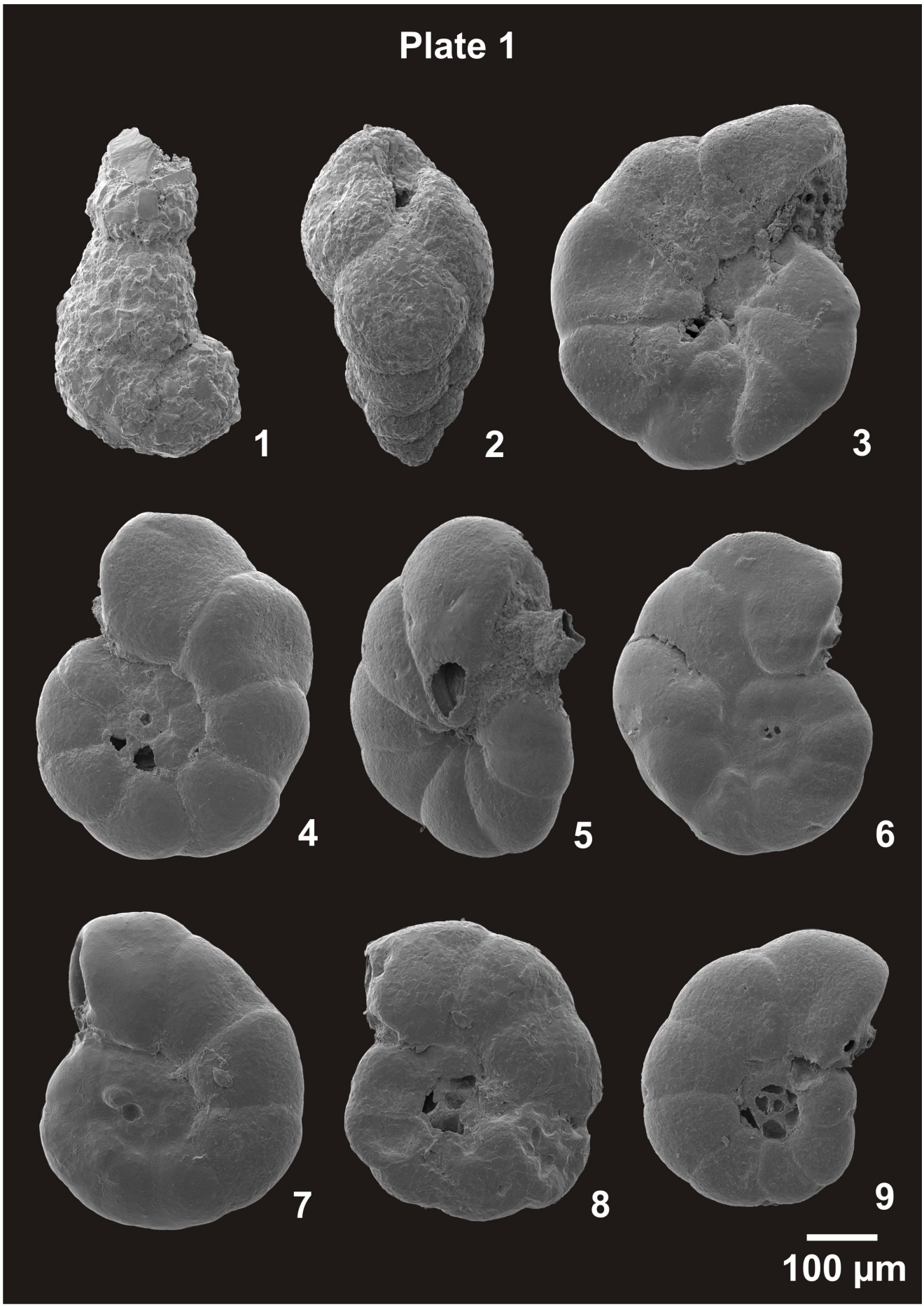


Plate 1
1
2
3
4
5
6
7
8
9
100 µm

Plate 2

Fig. 1-8: *Trochammina inflata*

1: umbilical view, 140x, Isle of Wight (IW north).

2: spiral view, 100x, Isle of Wight (IW south).

3: umbilical view with feeding tube, 100x, Isle of Wight (IW north).

4: spiral view, 100x, Tollesbury (T VI S 8).

5: spiral view, 100x, Two Tree Island (TII P 6).

6: spiral view, dented, 160x, Loch Riddon (LR grazed).

7: spiral view, 100x, Kyleakin (KY P 6).

8: spiral view, 160x, Gann (G E 1).

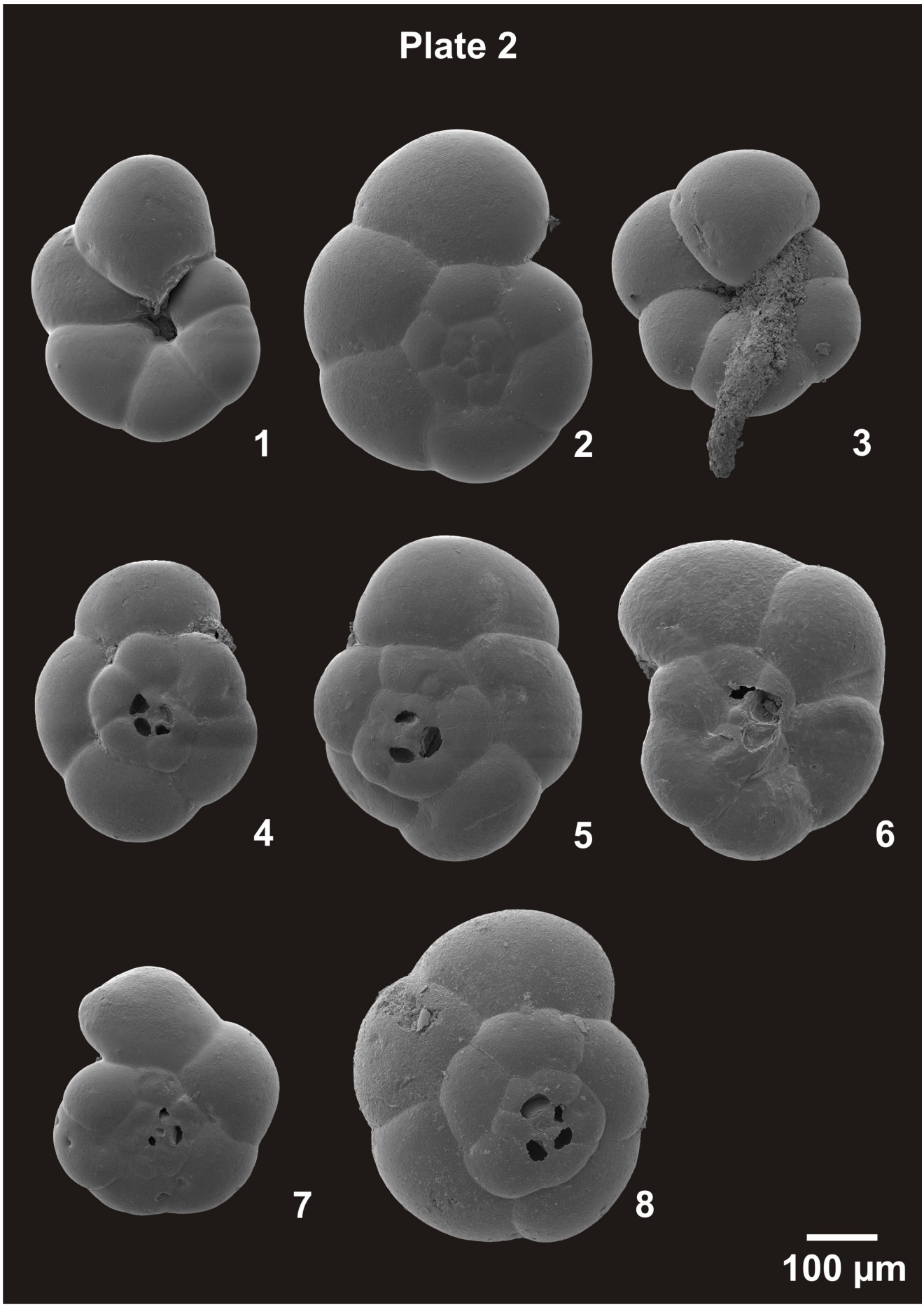


Plate 2
1
2
3
4
5
6
7
8
100 µm

Plate 3

Fig. 1-4: *Haplophragmoides wilberti*

1: lateral view, 160x, Isle of Wight (IW north).

2: lateral view, deflated, 190x, Isle of Wight (IW south).

3: lateral view, 160x, Loch Riddon (LR upper).

4: lateral view, 190x, Kyleakin (KY core I sur).

Fig. 5-9: *Miliammina fusca*

5: lateral view, 190x, Gann (G P 1).

6: lateral view, 140x, Isle of Wight (IW north).

7: lateral view, 160x, Loch Riddon (LR grazed).

8: lateral view, broken, 140x, Kyleakin (KY core I sur).

9: lateral view, 190x, Two Tree Island (TTI P 6).

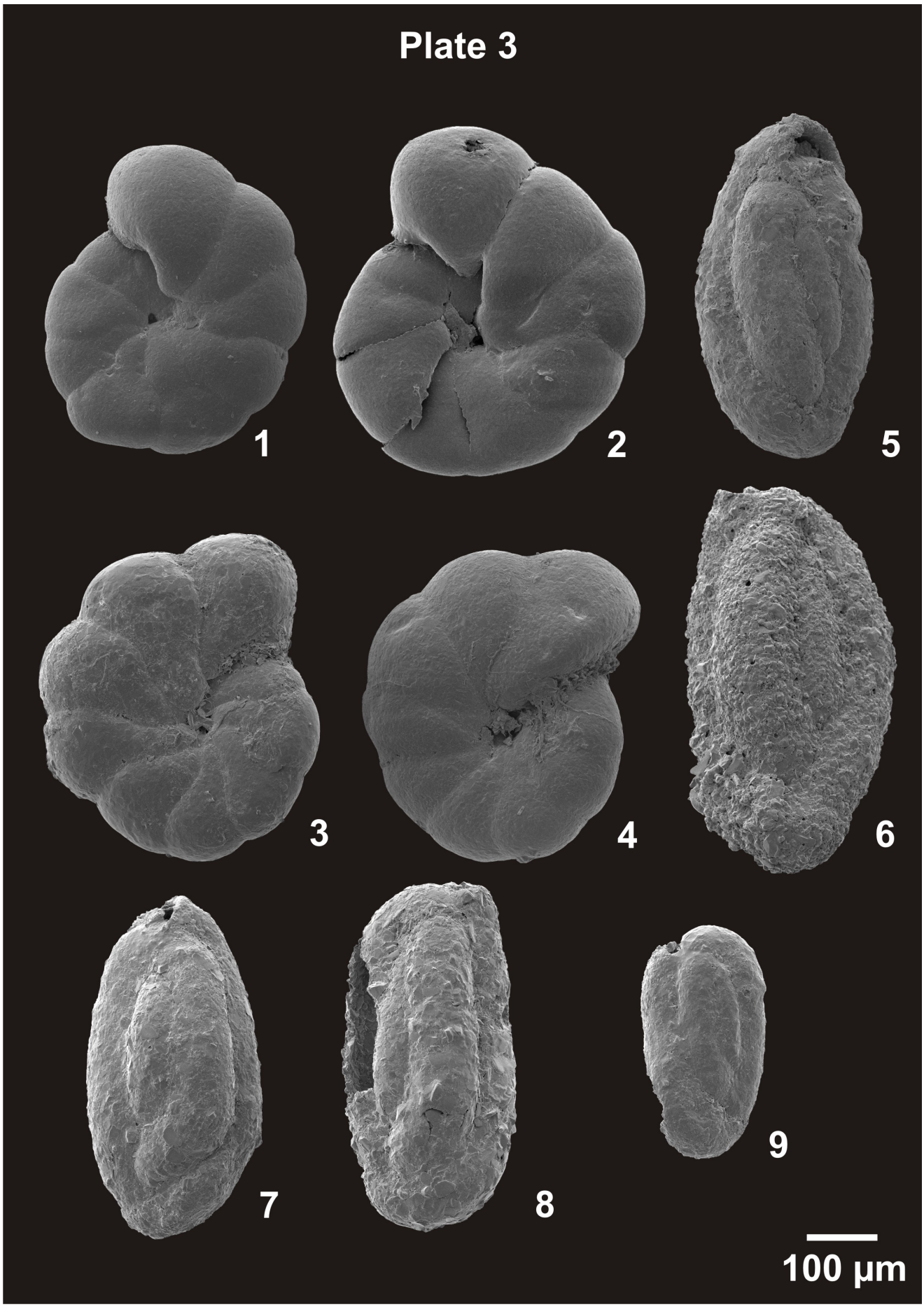


Plate 3
1
2
5
3
4
6
7
8
9
100 µm

Plate 4

Fig. 1-3: *Reophax moniliformis*

1: lateral view, 100x, Isle of Wight (IW north).

2: lateral view, 160x, Tollesbury (T XII SP 3).

3: lateral view, 100x, Tollesbury (T XII SP 4).

Fig. 4-5: *Cornuspira involvens*

4: lateral view, 190x, Isle of Wight (IW north).

5: lateral view, broken, 190x, Gann (G A 1).

Fig. 6: *Quinqueloculina oblonga*

6: lateral view, 190x, Gann (G P 1).

Fig. 7-8: *Quinqueloculina* spp.

7: lateral view, 160x, Isle of Wight (IW north).

8: lateral view, 190x, Tollesbury (T V A 17).

Fig. 9-11: *Ammonia* cf. *beccarii*

9: umbilical view, 190x, Isle of Wight (IW north).

10: umbilical view, 190x, Isle of Wight (IW north).

11: umbilical view, 190x, Isle of Wight (IW north).

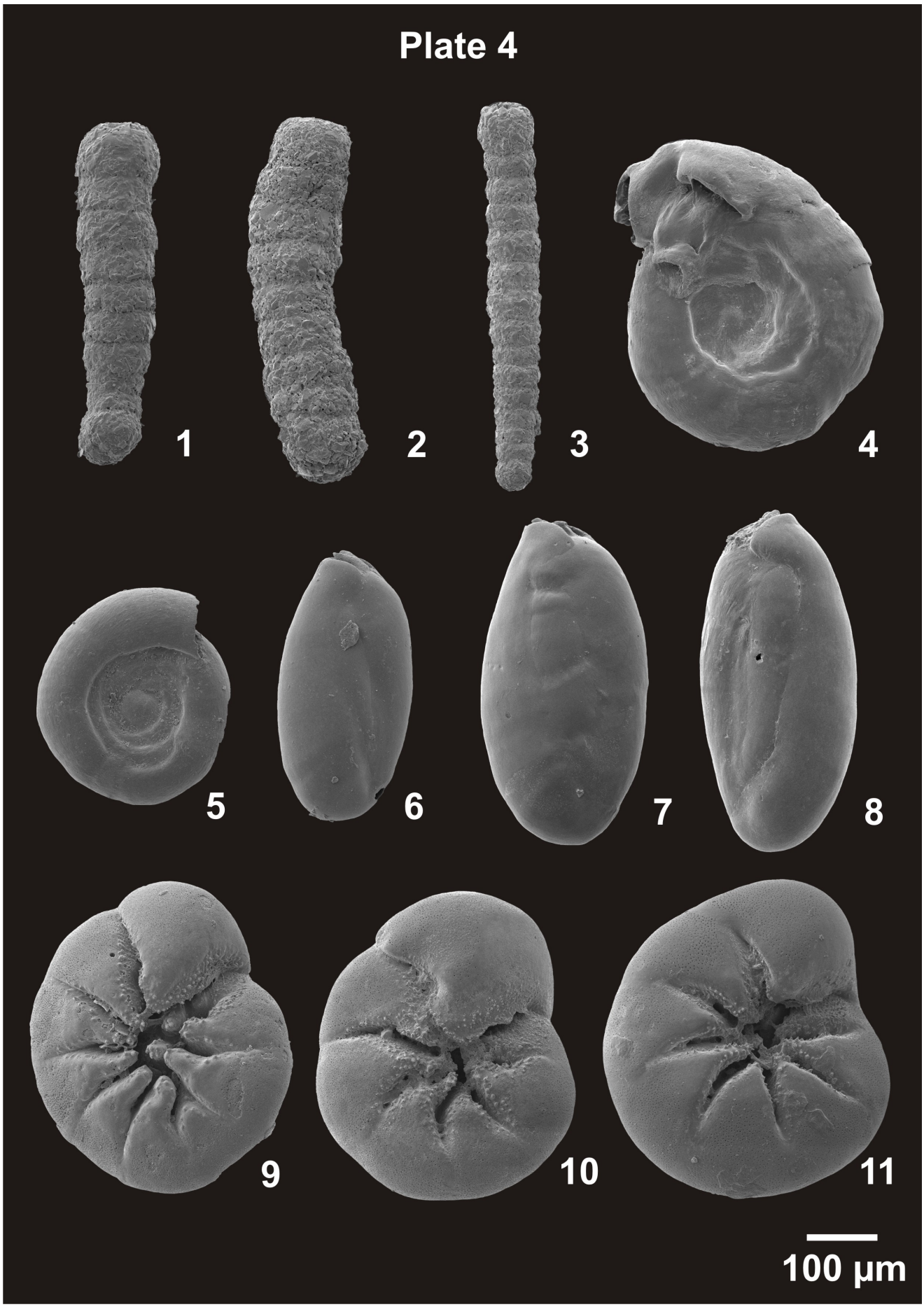


Plate 4
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100 µm

Plate 5

Fig. 1: *Elphidium williamsoni*

1: lateral view, 190x, Gann (G S1).

Fig. 2-5: *Elphidium* spp.

2: lateral view, 160x, Isle of Wight (IW north).

3: lateral view, 140x, Isle of Wight (IW south).

4: lateral view, 160x, Tollesbury (T VI S 8).

5: lateral view, 190x, Loch Riddon (LR sand).

Fig. 6-: *Haynesina germanica*

6: lateral view, 160x, Isle of Wight (IW north).

7: lateral view, 160x, Tollesbury (T XII SP 4).

8: lateral view with 'turbellarian egg case', 160x, Isle of Wight (IW north).

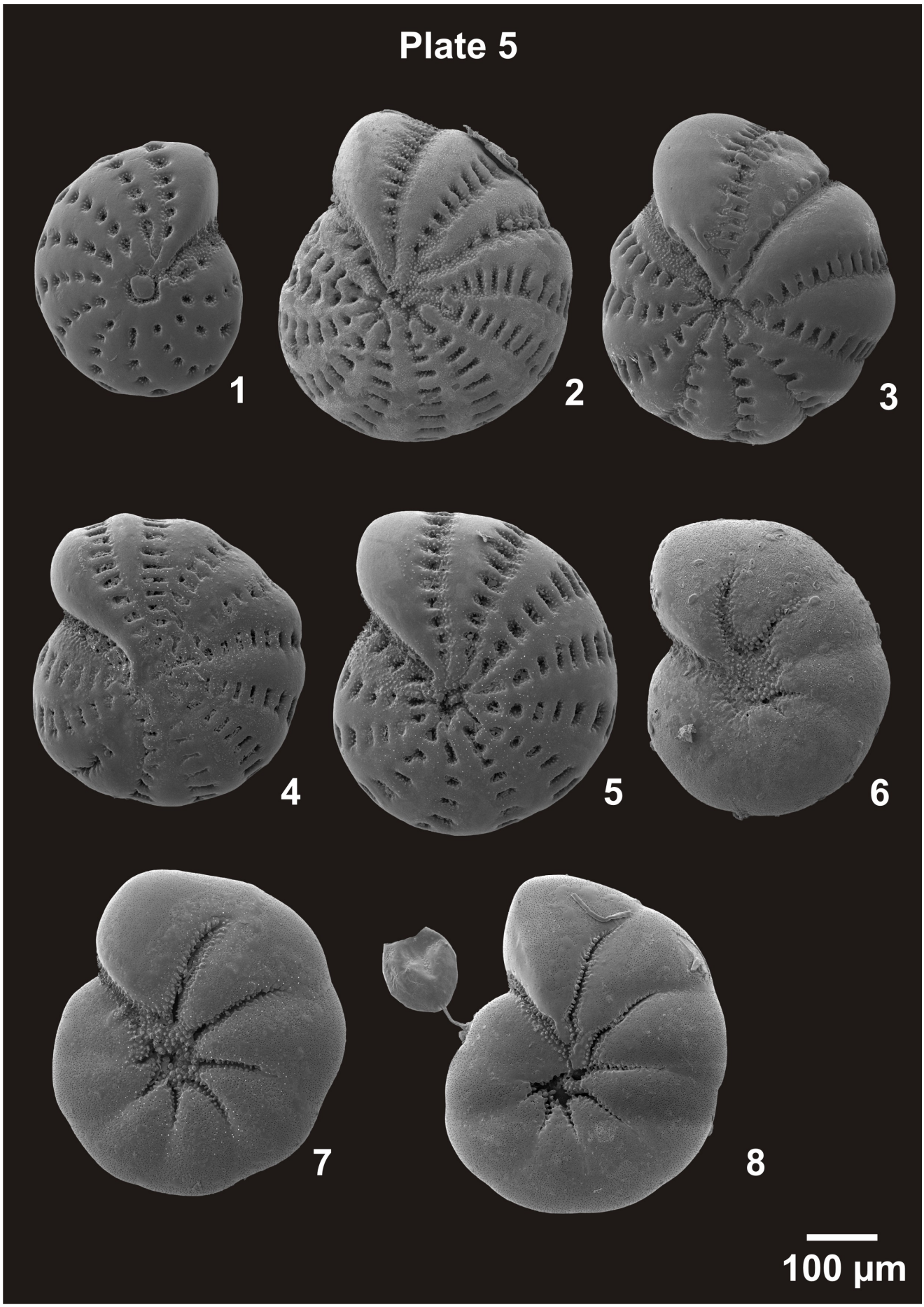
Plate 5
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5.2. Ostracoda

A total of 8 196 specimens of Ostracoda were examined, belonging to 11 families and 21 genera. They belong all to the subclass Podocopa (chapter 1.3.3). The used classification is after Horne (1980), Athersuch et al. (1989), Horne & Boomer (2000), Cabral & Loureiro (2013) as well as several articles in the journal *A Stereo-Atlas of Ostracod Shells*. Furthermore, for the few rare species publications like Horne et al. (2004) for *Terrestricythere*, Horne & Robinson (1982) for *Loxoconcha malcomsoni*, Athersuch et al. (1989) for *Hemicythere rubida* and Athersuch & Horne (1986) for *Xestoleberis labiata* were used. D.J. Horne and J.E. Whittaker also examined the picked species in order to discuss and verify the identifications.

In the beginning, Ostracoda studies were focused on basic (geography, distribution and taxonomy) and applied research (studies for oil exploration). From this time, publications appeared with mostly one aspect of Ostracoda research, like a local geographic area or ecological niche, e.g. the deep-sea. The published monographs were about deep-sea Ostracoda by Brady (1880), the Mediterranean Ostracoda within the Bay of Naples by Müller (1894) and the Ostracoda of Norway by Sars (1922-1928). Later publications were on the ecology of marine Ostracoda by Elofson (1941; translated into English 1969). Parallel to this monograph, a seminal volume of freshwater Ostracoda, of the Fauna of the USSR by Bronstein (1947; translated into English in 1988) was published. However, illustrations and descriptions were limited and the palaeoecological knowledge and taxonomy needed improvement. The first attempt at it was the combined works of Van Morkhoven with Post-Palaeozoic and Benson with Palaeozoic Ostracoda. Here, the "Post-Palaeozoic Ostracoda, their morphology, taxonomy and economic use" by Van Morkhoven (1962-3) was widely used by ostracodologists. In Van Morkhoven's two Volumes, the Ostracoda knowledge of E. Triebel as well as Kesling's (1951) illustrations and Ostracoda ontogeny study was combined. Additionally, Van Morkhoven's volumes were complemented by 'Ostracoda' volume Q of the American Treatise of Invertebrate Palaeontology by Benson (1961), with the criteria for taxonomic groupings for Palaeozoic Ostracoda (Brasier, 1970; Haslett, 2000; Danielopol et al., 2015). Between 1961 and 1963, Puri worked on improving and revising the taxonomy and the distribution of the Ostracoda fauna of the Bay of Naples. Hartmann (1964) then suggested a unified classification system for fossil and recent Ostracoda which was expanded later. In it, Hartmann & Puri (1974) dealt with the systematic as well as the ecological distribution of marine Ostracoda.

One practical change in Ostracodology was the use of the Scanning Electron Microscope (SEM) which became then the standard method regarding taxonomic descriptions. Here, Sylvester-Bradley's (1973 onwards) series 'A Stereo-Atlas of Ostracod Shells' is worthy of mention, which is still used. Since Benson (1961) and the ongoing revision of the Treatise on Invertebrate Palaeontology by Moore (1961), the Ostracoda classification "has been in some flux over the recent years" (Haslett, 2000). At a later "time, the focus was to catalogue

and morphologically describe the surprisingly rich ostracod fauna from both marine and limnic environments" (Danielopol et al., 2015). From this period, books for Ostracoda identification were produced by Bate & Robinson (1978), Oertli (1985), McKenzie et al. (1989) and Whittaker & Hart (2000). And for Britain Athersuch et al. (1989) and Henderson (1990) were describing the living Ostracoda. These also presented taxonomic keys to distinguish species from the Quaternary to Recent. Other keys can be found in Griffiths & Holmes (2000), Meisch (2000) and Horne & Boomer (2000). "Databases local and regional advanced the understanding beside the better analytical techniques" (Haslett, 2000). Benson's unsuccessful attempt of creating an Ostracoda data-bank led to Kempf's Cologne Database (1980-2013). The newer data-base OMEGA (Ostracod Meta-database of Environmental and Geographic Attributes) by Horne follows the idea of taxonomic harmonisation on a global scale. This means that Ostracoda "should be identified by clear morphological traits visible in many populations within large geographical areas" (Danielopol et al., 2015). The idea behind is that, instead of using minimal characteristics for species definition, taxa can also be used for ecological purposes. This means that populations show similar biological and ecological attributes. This works also on fossil taxa like *Cypridea* as seen in Sames & Horne (2012).

Nowadays, molecular research explores the concept of integrative taxonomy, where a species with its genetics, morphology, ecology, behaviour and distribution are studied. To mention here is the SexAseX project (2004-2008) (Danielopol et al., 2015) and its focus on a widespread European species *Eucypris virens*. The reasons behind its ability to switch from a sexual to parthenogenetic population were studied. As a result, cryptic species were produced and it was discovered that environmental conditions were related to its reproduction mode (Adolfsson et al., 2009; Schmit et al., 2013). Using the same conceptual approach, it was possible to produce an "'integrative taxonomy' emerged for an Australian Ostracod *Bennelongia*" (Danielopol et al., 2015). From this phylogenetic linage, new species were described (Martens et al., 2012; De Deckker & Martens, 2013). In conclusion, as for Foraminifera, no unified classification for Ostracoda exists. However, the literature as mentioned above, shows that the systematic is still in progress. And with the help of new methods (genetics) the knowledge of what and how a species is defined becomes clearer. However, until a new Ostracoda systematic exists, to identify Ostracoda species, often several references have to be used. For any information on species distribution data-bases are the best option, where data have been collected over a long period of time.

Considering the various literature on Ostracoda systematics, as mentioned above, here the attempt was made to use the up-to-date information for the listed Ostracoda. Due to the limited information regarding brackish-water Ostracoda, besides the Stereo-Atlas, journals had to be used for newer systematic data, especially for rare species. For a list about the absolute abundance of all Ostracoda species per sample, see appendix E. Supplementary, images of the most common and rare species are shown at Plate 6 to 10.

Class: OSTRACODA Latreille, 1806

Subclass: PODOCOPA Sars, 1866

Order: PODOCOPIDA Sars, 1866

Suborder: CYTHEROCOPINA Gründel, 1967

Superfamily: CYTHEROIDEA Baird, 1850

Family: CUSHMANIDEIDAE Puri, 1974

Genus: *Pontocythere* Dubowsky, 1939

5.2.1. *Pontocythere elongata* (Brady, 1868)

1980 *Pontocythere elongata* (Brady); Horne: 74, pl.18, fig.10-11; pl.19, fig.5.9(b).

2013 *Pontocythere elongata* (Brady); Cabral & Loureiro: 140, pl.1, fig.13.

Occurrence: *Pontocythere elongata* was only found in samples (TCP 22, 28, 31, 34 and 37) at a depth below 2 m of the sediment core from Two Tree Island. Only juvenile valves were found. In the deepest sample (TCP 37), adult valves were also collected.

Family: CYTHERURIDAE Müller, 1894

Genus: *Cytherura* Sars, 1866

5.2.2. *Cytherura gibba* (Mueller, 1785)

1973 *Cytherura gibba* (O.F. Müller); Whittaker: 274, pl.274, fig. 1a-2b; pl.276, fig. 1a-2b; pl.278, fig.1a-4b; pl.280, fig. 1a-3b.

Occurrence: *Cytherura gibba* was found at three study sites. The first site, at Tollesbury, one juvenile valve was collected from a surface sample (CR 2). The second sampling site, at Two Tree Island, this species was also only collected from a *Puccinellia* surface sample (P 6), which was also a juvenile valve. The third location, at Gann, also one juvenile valve was found in a *Salicornia* surface sample (S 1). All samples, where *C. gibba* was found, were mid to low marsh samples. This exclusively brackish species occurs around Britain, and also from north-west Europe to the Baltic (Athersuch et al., 1989).

Genus: *Cytheropteron* Sars, 1866

5.2.3. *Cytheropteron* cf. *depressum* Brady & Norman, 1889

2013 *Cytheropteron depressum* Brady & Norman; Cabral & Loureiro: 140, pl.1, fig.16.

Occurrence: This species was found only in three sediment core samples (TCP 16, TCP 22, TCP 34) from Two Tree Island. Here, only juvenile valves were collected.

Even through, only juveniles were found, it showed its typically rounded and elongated, less protruding truncated alae. Also, the valve form had a more rectangular (sub-rhomboidal) form with a more pointed posterior margin, as seen in Cabral & Loureiro (2013).

5.2.4. *Cytheropteron* cf. *monoceros* Bonaduce, Ciampo & Masoli, 1976

2013 *Cytheropteron monoceros* Bonaduce, Ciampo & Masoli; Cabral: 140, pl.1, fig.19.

Occurrence: This species was also only found in sediment core samples (TCP 25 and TCP 31) from Two Tree Island. Only juvenile valves were collected.

Cytheropteron cf. *monoceros* was identified due to its dominant protruding truncated alae. Also, a caudal process is posteriorly visible and the surface appears to be smooth. However, since only juvenile valves were found, and *Cytheropteron* is known for possessing conspicuously unequal valves, the identification is still uncertain.

5.2.5. *Cytheropteron punctatum* Brady, 1868

2013 *Cytheropteron punctatum* Brady; Cabral & Loureiro: 140, pl.1, fig.20.

Occurrence: As the two other species of *Cytheropteron*, this one was also only found in sediment core samples (TCP 25 to 37) from Two Tree Island. Although, the amount of found specimens was higher compared to the other species, only juvenile valves were collected.

Genus: *Hemicytherura* Elofson, 1941

5.2.6. *Hemicytherura* cf. *cellulosa* (Norman, 1865)

1980 *Hemicytherura cellulosa* (Norman); Horne: 86, pl.12, fig.1-7; fig.5.10(a).

1989 *Hemicytherura cellulosa* (Norman); Athersuch et al.: 204-205, fig.81; pl.6, fig.9.

2013 *Hemicytherura cellulosa* (Norman); Cabral & Loureiro: 140, pl.2, fig.10-11.

Occurrence: *Hemicytherura* cf. *cellulosa* was only found in the sediment core samples (TCP 28, TCP 34, TCP 37) from Two Tree Island. Here, juvenile carapaces as well as valves were collected.

Discussion: It is known that adults and juveniles show a different surface ornamentation which is added at the final moult (Whittaker, 1973a). This is also true for other species of this genera, like *Hemicytherura videns* (G.W. Müller). However, this species has not been previously recorded in Britain. Otherwise, it might be possible that juvenile forms of *Hemicytherura hoskini* Horne, 1981 were present with its coarser ornamentation. *H. cellulosa* is a marine littoral, phytal species which is common in Britain, and also in north-west Europe (south France to Norway) (Athersuch et al., 1989).

Genus: *Microcytherura* G. W. Müller, 1894

5.2.7. *Microcytherura* sp.

Occurrence: Two Tree Island, the only study site were representatives of the genus *Microcytherura* were collected from the sediment core (samples TCP 31 to TCP 37). Here, only juvenile valves were found.

Discussion: It was not possible to identify any species since the juvenile valves represented instar A-2 and below. Therefore, all collected specimens were summarised as *Microcytherura* sp..

Genus: *Semicytherura* Wagner, 1957

5.2.8. *Semicytherura* spp.

Occurrence: Two Tree Island, the only study site were representatives of the genus *Semicytherura* were collected. One juvenile valve was found in the low marsh sample (S 6). Other specimens of this genus were collected from the sediment core (samples TCP 25 to TCP 37). Here, juvenile carapaces and valves were found.

Discussion: Since only juvenile forms were found, it was not possible to distinguish any species. Therefore, all specimens were summarised as *Semicytherura* spp.. However, it was observed that the juveniles might belong to three or five different species.

Family: CYTHERIDEIDAE Sars, 1925

Genus: *Cyprideis* Jones, 1857

5.2.9. *Cyprideis torosa* (Jones, 1850)

Plate 6, fig. 1-4

1974 *Cyprideis torosa* (Jones); Kilenyi & Whittaker: 22, pl.22, fig. 1a-3b; pl.24, fig.1a-3b; pl.26, fig.1a-4b; pl.28, fig.1a-3b; pl.30, fig.1a-2b; pl.32, fig.1a-3b.

1980 *Cyprideis torosa* (Jones); Horne: 75, pl.15, fig.3-4.

1989 *Cyprideis torosa* (Jones); Athersuch et al.: 114-115, fig.12A-C;, 44, pl.31, fig.1, 2.

2000 *Cyprideis torosa* (Jones); Horne & Boomer: 199.

2013 *Cyprideis torosa* (Jones); Cabral & Loureiro: 140, pl.1, fig.14.

Occurrence: This species was found at four study sites. The fist location, at Tollesbury, it was found on the algae (samples AA 2 to AA 5) which was growing on *Atriplex*. Here, only a few juvenile valves were collected. The majority of this species was living in the salt pans of the lower marsh (SP 4 and SP 8). In it, adult carapaces as well as juveniles with valves were identified. The second location, at Two Tree Island, *C. torosa* was collected only from the sediment core throughout (sample TCP 7, TCP 710 and TCP 716 to TCP 737). The two upper samples contained only juvenile valves. The deeper samples contained adult carapaces as well as juveniles, including their valves. The third location, at the northern site of the Isle of Wight, one female adult valve was collected at the outer most samples (R 1). Also, one female carapace as well as one male valve together with juveniles were collected from the algae growing on *Atriplex*. At the fourth location, at Kyleakin, it was the only found Ostracoda species. Here, it was living in the salt pan as well as on the mudflat, including carapaces and valves, together with their juveniles forms.

Discussion: It is noteworthy, that all found *Cyprideis torosa* had a smooth surface without any nodes (van Harten, 2000). This was also the case from the specimens found at the intertidal area in the Bristol Channel (Horne, 1980) as well in Portugal (Cabral & Loureiro, 2013).

Family: HEMICYTHERIDAE Puri, 1953

Genus: *Aurila* Pokorny, 1955

5.2.10. *Aurila woutersi* Horne, 1986

1986 *Aurila woutersi* sp. nov. Horne: 33, pl.13, fig.1a-3b.

1989 *Aurila woutersi* Horne; Athersuch et al.: 160, fig.14C; 64, pl.5, fig.2.

2013 *Aurila woutersi* Horne; Cabral & Loureiro: 143, pl.4, fig.5.

Occurrence: It was found in only one sediment core sample (TCP 37) at Two Tree Island; the find consists only of juvenile left and right valves.

Discussion: Although the found specimens were juveniles, the valve outline shows more characteristics of *Aurila woutersi* than *Aurila convexa*. This means that the anterior is more rounded rather than decline to a rounded form. Furthermore, the ornamentation was denser pitted as well as less coarse. Also, the outer margin on the ventral side was stronger dented than by *A. convexa*. The overall appearance of the valves were more oval than quadratic. However, the valves were juveniles and only images of juvenile forms of *A. convexa* could be found. Therefore, the possibility exists that they could also be juveniles of *A. convexa*, since the adult from differs from the juveniles and no adults were found. One reason to suspect this, is the find of two varieties as described by Horne (1980) which also occurred at the Thames Estuary. One of the varieties was later described as a new species *Aurila woutersi*. This species is not known outside Britain, it is a phytal, littoral to shallow sublittoral which appears in south Britain (Athersuch et al., 1989).

Genus: *Hemicythere* Sars, 1925

5.2.11. *Hemicythere rubida* (Brady 1868)

Plate 6, fig. 5-8

1868 *Cythereis rubida* sp. nov. (Brady) 353-495, pl.19.

1989 *Hemicythere rubida* (Brady); Athersuch et al.: 154, fig.61; pl.4, fig.9.

2000 *Hemicythere rubida* (Brady); Horne & Boomer: 198.

2013 *Hemicythere rubida* (Brady); Cabral & Loureiro: 143, pl.4, fig.8.

Occurrence: This rare species was found only at two study sites. The first site, at Tollesbury, it was found as valves (adults and juveniles), except for one carapace (see Plate 6, fig. 7). The majority

of the samples, were it was found, were at mid marsh (A 17, A 1718). Only one sample belongs to the low marsh (CR 28). At the second sampling site, living specimens of *Hemicythere rubida* were found. It was collected from the northern as well as southern site of the Isle of Wight. Besides a few valves, adults and juveniles, among the *Atriplex* zone, the highest abundance was discovered at mid-high marsh (Mix 1 to Mix 6). Here, the plants mainly consisted of *Atriplex* and *Puccinellia*.

Discussion: *Hemicythere rubida* is a rare brackish-water Ostracoda. It has a distinct reddish brown colour when alive and rectangular shape with rounded post and anterior margins. The shell surface is roughly but evenly pitted with reticulation (Horne & Boomer, 2000). The two locations were this species was found, are probably the only two living British records since Brady. No *H. rubida* was found in Portugal (Cabral & Loureiro, 2013). Athersuch et al (1989) also describe appearances of this species in west Scotland, south England and Iceland. It can also be confused with *Cytheromorpha fuscata* (Athersuch et al., 1989).

5.2.12. *Hemicythere villosa* (Sars, 1866)

1981 *Hemicythere villosa* (Sars); Athersuch & Whittaker: pl.28, fig.1a-3b; pl.30, fig.1a-3b.

1989 *Hemicythere villosa* (Sars); Athersuch et al.: 152, fig.14B; 60, pl.4, fig.8.

2013 *Hemicythere villosa* (Sars); Cabral & Loureiro: 143, pl.4, fig.9.

Occurrence: Only a few specimens of *Hemicythere villosa* were found in the sediment core (samples TCP 25, TCP 28, TCP 34, TCP 37) from Two Tree Island. Here, only juvenile valves were collected.

Discussion: Compared to *Hemicythere rubida*, *H. villosa* has a more oval shaped appearance. Also, its surface is more roughly ornamented (Athersuch & Whittaker, 1981). *H. villosa* is a littoral to shallow sublittoral species living on algae and sediment. It is was found around Britain as well as in outer estuaries in north-west Europe (Athersuch et al., 1989).

Genus: *Heterocythereis* Elofson, 1941

5.2.13. *Heterocythereis albomaculata* (Baird, 1838)

1979 *Heterocythereis albomaculata* (Baird); Athersuch & Whittaker: pl.118, fig.1a-3b; pl.120, fig.1a-4b; pl.122, fig.1a-4b; pl.124, fig.1a-5b.

1989 *Heterocythereis albomaculata* (Baird); Athersuch et al.: 165, fig.66; pl.5, fig.4.

2013 *Heterocythereis albomaculata* (Baird); Cabral & Loureiro: 143, pl.4, fig.18.

Occurrence: This species was only found at Two Tree Island sediment core. Here the top sample (TCP 1) contained juvenile valves only. This also is the case in deeper samples (TCP 16 and TCP 22), like at 2.8 m depth (TCP 28). The same is true for the samples at 3 m, (TCP 31, TCP 34 and TCP 37) where also only juvenile valves were found.

Discussion: The strong sexual dimorphism is clearly visible, even in instar A-1 where only males were identified. This species was clearly recognised, also its juvenile forms, because of images (adult and juveniles) from Horne (1980). *H. albomaculata* is a phytal, littoral and sublittoral common marine species which is often abundant in rock pools (Cabral & Loureiro, 2013). Its distribution ranges from north Norway to the Mediterranean, and is also known from Britain and the Azores (Athersuch et al., 1989).

Family: LEPTOCYTHERIDAE Hanai, 1957

Genus: *Leptocythere* Sars, 1928

5.2.14. *Leptocythere baltica* Klie, 1929

1985 *Leptocythere baltica* Klie; Horne & Whittaker: pl.94, fig.1a-3b; pl.96, fig.1a-3b.

1989 *Leptocythere baltica* Klie; Athersuch et al.: 98, fig.34; pl.1, fig.5.

2000 *Leptocythere baltica* Klie; Horne & Boomer: 202.

2013 *Leptocythere baltica* Klie; Cabral & Loureiro: 145, pl.5, fig.4.

Occurrence: *Leptocythere baltica* was identified at two sampling sites: Tollesbury and Gann. At Tollesbury, one juvenile carapace was found at high marsh (E 9). The highest abundance, only juvenile valves, was found at low marsh (sample (CB 1) and a few more among *Salicorna* (S 4). At Gann, the collected specimens consisted of one adult carapace as well as valves. They were found at mid marsh (A 1).

Discussion: Since most found specimens of *Leptocythere baltica* were juveniles, they also could be mistaken for other species, except the adults found at Gann. Especially, *L. ciliata* and *L. porcellanea* also have similar shapes and a smooth surface. Therefore, the possibility exists that a few juvenile forms could be mixed up with other species of the same genus. As for its distribution, so far it has been found on preferably sandy or silty substrate of the tidal flat as well as low marsh. It is a marine species with the ability to tolerate reduced salinity (Horne & Boomer, 2000; Cabral & Loureiro, 2013).

5.2.15. *Leptocythere castanea* (Sars, 1866)

Plate 7, fig. 1-8

1980 *Leptocythere castanea* (Sars); Horne: 76, pl.6, fig.9-12, fig.5.8(e).

1989 *Leptocythere castanea* (Sars); Athersuch et al.: 100, fig.35; pl.1, fig.6.

2000 *Leptocythere castanea* (Sars); Horne & Boomer: 201.

2013 *Leptocythere castanea* (Sars); Cabral & Loureiro: 145, pl.5, fig.4.

Occurrence: This species was collected from five study sites. The first, at Tollesbury, here it was only found in the surface samples, were it is most abundant in the low marsh (CR and CB samples). Adult carapaces as well as juveniles, including valves were identified in the low marsh. Male adults were also collected from the outer lying salt pans (SP 4 and SP 8) as well as one juvenile valve found among the *Salicornia* sample (S 2). A few carapaces and valves, adults and juveniles, were collected from the mid marsh as well (A 2, A 28, A 32, A 33 and A 37). Here, mostly juvenile valves, including two adult carapaces were found. At the second location, Two Tree Island, this species was found in the low marsh (S 6) as well as the sediment core. In the *Salicornia* sample (S 6), only juvenile valves and carapaces were found. The same is true for the sediment core samples (TCP 10 to TCP 31 and TCP 37), except that adult forms were also present. At the third locality, the Isle of Wight, *L. castanea* was found north and south of the Western Yar Estuary. The highest abundance was collected at the outer rim of the marsh (R 1, R 3, R 4), with carapaces and valves ranging from juveniles to adults. At the fourth sampling site Gann, this species was found only at low marsh (S 1). The find consisted of one adult carapace as well as two juvenile valves. The last location, Loch Riddon, only one adult carapace was found at the sandy mudflat (sample: sand).

Discussion: *Leptocythere castanea* is an exclusive brackish water species (euryhaline), with no clear preference of its substrate. This species indicates inner estuarine / saltmarsh environment (Athersuch et al., 1989). Therefore, it can be found on sand, but preferably on mud or algae. Also remarkable is its possibility to lay resting eggs during autumn in salt pans. Despite this ability, it may have one generation per year (Horne & Boomer, 2000). Its known distribution ranges from north-west Europe (Bay of Biscay) to Norway and the Baltic, and was also found in south Greenland (Athersuch et al., 1989).

5.2.16. *Leptocythere ciliata* Hartmann, 1957

Plate 7, fig. 9-11

1957 *Leptocythere lacertosa ciliata* nov.subsp. Hartmann: 110-111, text-fig. 1, 2, 4, 6.

1980 *Leptocythere ciliata* Hartmann; Horne: 79, pl.8, fig.1-3, fig.5.8(b).

2013 *Leptocythere ciliata* Hartmann; Cabral & Loureiro: 145, pl.5, fig.6.

Occurrence: *Leptocythere ciliata* was found at four study sites. The first, were it also was found alive, was at Tollesbury. Here, adult and juvenile carapaces and valves were found living at mid marsh. A few, mostly juvenile, valves were also collected from the low marsh (appendix E). At Two Tree Island, one adult carapace was found at low marsh (S 6) as well as one adult valve in the first sample of the sediment core (TCP 1). On the Isle of Wight, *L. ciliata* was collected only from the northern site. Here, only adult carapaces were found mostly between the low marsh (R 1, R 2, R 3) and mid marsh (Aas 1, Aas 2, Aas 4, Mix 5). The fourth location, at Gann, this species was found only at low marsh (S 1). Here, one adult and two juvenile carapaces were identified.

Discussion: *Leptocythere ciliata* is, compared to other *Leptocythere* as well as other Ostracoda species, very small. Therefore, it had taken some difficulties to distinguish between this species and other *Leptocythere* juveniles. Typically for this species are its often three or more 'ribs' at the anterior margin. The rest of its surface is mostly smooth, but can show some pitting towards the ventral site. This also distinguishes it from *L. lacertosa*. Sometimes, *L. ciliata* shows a faint dorsomedian sulcus, as it is common for *L. psammophila*. *L. ciliata* is a brackish water species which has been found from the tidal flat to high marsh (Cabral & Loureiro, 2013).

5.2.17. *Leptocythere fabaeformis* (G. W. Müller, 1894)

Plate 7, fig. 12-14

1894 *Cythere fabaeformis* Müller: 1-404.

1957 *Leptocythere fabaeformis* (Müller); de Vos.

2013 *Leptocythere fabaeformis* (Müller); Cabral & Loureiro: 145, pl.5, fig.8.

Occurrence: This species was only found at the northern site of the Isle of Wight. Here, it was collected from the outer rim of the marsh (R 1, R 3, R 4) as well as one adult carapace was found at

mid marsh (Aas 1). In the remaining samples, also only adult carapaces were found. No valves or juvenile specimens were found.

Discussion: This species has large adults, compared to other *Leptocythere* species. It has a faint dorsomedian sulcus and a prominent posteroventral alar protuberance which is also known from *L. porcellanea* and *L. castanea*. Further, the surface is ornamented with reticulation and scattered pitts are also visible. The broad anterior margin also contains 'ribs'. *L. fabaeformis* is a rare brackish water Ostracoda (euryhaline) and is known as a phytal / littoral marine species. So far, its distribution ranges from the Mediterranean to western Europe, with its northern limit in W France. In Portugal it has been found in the tidal flat as a subordinate species (Cabral & Loureiro, 2013). The only living British record is now known from the northern Western Yar Estuary on the Isle of Wight.

5.2.18. *Leptocythere porcellanea* (Brady, 1869)

Plate 8, fig. 1-6

1980 *Leptocythere porcellanea* (Brady & Robertson); Horne: 77, pl.6, fig.13-14.
1985 *Leptocythere porcellanea* (Brady); Horne & Whittaker: pl.100, fig.1a-3b; pl.102, fig.1a-3b; pl.104, fig.1a-3b; pl.106, fig.1a-3b.
1989 *Leptocythere porcellanea* (Brady); Athersuch et al.: 104, fig.38; pl.2, fig.1, 2.
2000 *Leptocythere porcellanea* (Brady); Horne & Boomer: 201.
2013 *Leptocythere porcellanea* (Brady); Cabral & Loureiro: 145, pl.5, fig.13-14.

Occurrence: This species was found at five study sites. At the first one, Tollesbury, it was found alive with its highest abundance at mid marsh (appendix E). Dead specimens were also collected from the low marsh. At Two Tree Island, the second site, *L. porcellanea* was found at high to low marsh. Its highest abundance, with mostly adult carapaces (alive), were at the low marsh (S 6). Furthermore, it was collected from the sediment core (TCP 7 to TCP 28 and TCP 34). Here, a mix of adult and juvenile carapaces as well as valves were identified. The third site, it was collected only at the northern part of the Isle of Wight location. At this site, it was most abundant at low (R 1, R 3, R 4 and L 1, L 2) and mid marsh (Aas 1, Aas 2, Aas 3, Aas 4). Living specimens were found at both elevations which consisted mostly of adult carapaces. Hardly any juveniles were found. The fourth location, at Gann, this species was only found in the mid (A 1) and low marsh (S 1) sample. Here, mostly juvenile valves were found, only few carapaces and no adult forms. The fifth site, it was found in the

sediment core NNC 17 from Holkham. At a depth of 4 and 7 m, only few adult valves were found. However, due to sample processing, the valves were overgrown with gypsum crystals and not easy to identify.

Discussion: *Leptocythere porcellanea* is a true brackish water species which can be found preferably on muddy substrate (Horne & Boomer, 2000). This species indicates inner estuarine / saltmarsh environment and has been found in north-west Europe to the Baltic (Athersuch et al., 1989). In the Tollesbury samples, some specimens of this species could also be *Leptocythere lacertosa* .

5.2.19. *Leptocythere psammophila* Guillaume, 1976

1980 *Leptocythere psammophila* Guillaume; Horne: 76, pl.6, fig.5-8, fig.5.8(f).

1988 *Leptocythere psammophila* Guillaume; pl.124, fig.1a-5b; pl.126, fig.1a-5b.

1989 *Leptocythere psammophila* Guillaume; Athersuch et al.: 105, fig.39; pl.1, fig.10.

2000 *Leptocythere psammophila* Guillaume; Horne & Boomer: 202.

2013 *Leptocythere psammophila* Guillaume; Cabral & Loureiro: 145, pl.5, fig.15.

Occurrence: The sediment core from Two Tree Island was the only study site were this species was found. Only juveniles valves, except one carapace, of *L. psammophila* were found at sample TCP 10 and TCP 25. The highest abundance was found in the deepest samples (TCP 34 and TCP 37). They contained female and male carapaces as well as juveniles, including their valves.

Discussion: *Leptocythere psammophila* is an outer estuarine species which prefers a sandy substrate (Horne & Boomer, 2000). However, it was also found in a low saltmarsh (Cabral & Loureiro, 2013). This species indicates outer estuarine environment and its distribution ranges from the Atlantic coast of France to the Baltic, including Iceland (Athersuch et al., 1989).

Family: LOXOCONCHIDAE Sars, 1925

Genus: *Elofsonia* Wagner, 1957

5.2.20. *Elofsonia baltica* (Hirschmann, 1909)

1973 *Elofsonia baltica* (Hirschmann); Whittaker: pl.194, fig.1a-2b; pl.196, fig.1a-3b; pl.198, fig.1a-4b, pl.200, fig.1a-4b.

1980 *Elofsonia baltica* (Hirschmann); Horne:82, pl.18, fig.3-6, fig.5.7(g).

1989 *Elofsonia baltica* (Hirschmann); Athersuch et al.: 182, fig.6I; 72, pl.6, fig.1.

2000 *Elofsonia baltica* (Hirschmann); Horne & Boomer: 199.

Occurrence: This species was found at two study sites: Tollesbury and Gann. At the first location, only juvenile valves were found at mid marsh (A 17 and AA 6). At Gann, also mostly juvenile valves were collected from the low marsh (S 1). Only one juvenile carapace was also found there.

Discussion: *Elofsonia baltica* is a common British species. It reproduces one or two generations within salinities from 1 to 30 ‰. Their resting eggs are known to survive even frost (Horne & Boomer, 2000). This shallow brackish water species is common in British estuaries and has also been known from north-west Europe (south-west France) to north Norway and the Baltic (Athersuch et al., 1989).

Genus: *Hirschmannia* Elofson, 1941

5.2.21. *Hirschmannia viridis* (O. F. Müller, 1785)

1975 *Hirschmannia viridis* (O.F. Müller); Whittaker: pl.150, fig.1a-3b; pl.152, fig.1a-3b; pl.154, fig.1a-3b; pl.156, fig.1a-4b.

1980 *Hirschmannia viridis* (O.F. Müller); Horne: 81, pl.8, fig.4-7, fig.5.7(c).

1989 *Hirschmannia viridis* (O.F. Müller); Athersuch et al.: 186, fig.74; pl.5, fig.10.

2000 *Hirschmannia viridis* (O.F. Müller); Horne & Boomer: 199.

2013 *Hirschmannia viridis* (O.F. Müller); Cabral & Loureiro: 145, pl.5, fig.21.

Occurrence: At Two Tree Island, this species was only found in the sediment core (samples TCP 22 to TCP 37). In all core samples, only juvenile valves were found, even though their abundance increases with depth. The same is true for the second location. At the northern part of the Isle of Wight, only one juvenile valve was found.

Discussion: “A euryhaline and eurythermic phytophilous species most commonly found in intertidal rockpools on British coasts, it also occurs in saltpans, particularly where filamentous green algae are abundant” (Horne & Boomer, 2000). It is a common phytal British species which occurs also from the Arctic to south-west France (Athersuch et al., 1989).

Genus: *Loxoconcha* Sars, 1966

5.2.22. *Loxoconcha elliptica* Brady, 1868

Plate 8, fig. 7-14

1976 *Loxoconcha elliptica* Brady; Athersuch & Whittaker: pl.100, fig.1a-3b; pl.102, fig.1a-3b; pl.104, fig.1a-5b; pl.106, fig.1a-3b.
1980 *Loxoconcha elliptica* Brady; Horne: 80, pl.9, fig.5-8, fig.5.9(c).
1989 *Loxoconcha elliptica* Brady; Athersuch et al.: 176, fig.4, 8, 10, 16, 70; pl.5, fig.8.
2000 *Loxoconcha elliptica* Brady; Horne & Boomer: 200.
2013 *Loxoconcha elliptica* Brady; Cabral & Loureiro: 145, pl.6, fig.3.

Occurrence: A single juvenile valve was found at the low marsh (CB 1) at Tollesbury. Also, only juveniles, were found in the surface samples at Two Tree Island. Here, valves were most abundant. Further, some specimens were collected also from the sediment core (TCP 13, TCP 22 to TCP 37). The first two samples only contain juvenile valves. Whereas, in deeper samples a mix of adult and juvenile carapaces and their valves were identified. The last location, at Gann, *L. elliptica* was found not only in all surface samples, but also in two from three sediment cores. In the surface samples, juvenile valves are dominating the Ostracoda assemblage. Only few carapaces, also from adults, were found. In one sediment core (T 3), one adult carapace was collected together with juvenile valves. The second core (T 4) container only juvenile valves.

Discussion: *Loxoconcha elliptica* is a true brackish water species confined to estuaries, lagoons and pools which prefers a muddy substrate (Athersuch et al., 1989). Occasionally, it can also be found on algae and mud (Cabral & Loureiro, 2013). Therefore, it is found on saltmarshes, preferably in creeks. Their eggs do not survive freezing, but continuous reproduction during summer allows this species to produce more than one generation (Horne & Boomer, 2000). It is a common species in Europe (around Mediterranean) (Athersuch et al., 1989).

5.2.23. *Loxoconcha malcomsoni* Horne & Robinson, 1985

Plate 9, fig. 1-10

1982 *Loxoconcha cuneiformis* Malcolmson (sic); Horne and Robinson: pl.22, fig.1a-3b; pl.24, fig.1a-4b.
1985 *Loxoconcha malcomsoni* Horne & Robinson: 157.

2000 *Loxoconcha malcomsoni* Horne & Robinson; Horne & Boomer: 201.

2013 *Loxoconcha malcomsoni* Horne & Robinson; Cabral & Loureiro: 145, pl.6, fig.4.

Occurrence: This rare saltmarsh species was found only at Tollesbury. Here, it was found alive with its highest abundance in the mid marsh (*Atriplex*). Also, fewer specimens were collected from the low marsh as well (CB and CR samples, also S 4).

Discussion: *Loxoconcha malcomsoni* was originally thought to be an extinct Pleistocene species until it was found alive in Britain by Horne & Boomer (2000). So far, only two other published locations are known: Isle of Wight (Western Yar Estuary) and at Stiffkey in Norfolk (Horne & Boomer, 2000). Even though samples were collected at both sites, especially on the Isle of Wight, no other specimens were identified. Only, from a saltmarsh in Portugal (Mira Estuary) it was found alive on the mid marsh (Cabral & Loureiro, 2013).

5.2.24. *Loxoconcha rhomboidea* (Fischer, 1855)

Plate 9, fig. 11

1976 *Loxoconcha rhomboidea* (Fischer); Athersuch & Whittaker: pl.82, fig.1a-3b; pl.84, fig.1a-8b; pl.86. fig.1a-4b; pl.88, fig.1a-5b.

1980 *Loxoconcha rhomboidea* (Fischer); Horne: 79-80, pl.9, fig.1-4, fig.5.9(d).

1985 *Loxoconcha rhomboidea* (Fischer); Athersuch, Horne & Whittaker:157, pl.2, fig.5-6.

1989 *Loxoconcha rhomboidea* (Fischer); Athersuch et al.: 174, fig.69; pl.5, fig.7.

2000 *Loxoconcha rhomboidea* (Fischer); Horne & Boomer: 200.

2013 *Loxoconcha rhomboidea* (Fischer); Cabral & Loureiro: 145, pl.6, fig.5.

Occurrence: In the sediment core (TCP 28) from Two Tree Island, only four juvenile valves were found. At the northern sampling site on the Isle of Wight few carapaces, juveniles and one adult, were collected on the outer rim of the saltmarsh (R 1).

Discussion: *Loxoconcha rhomboidea* is a common phytal, littoral / shallow sublittoral marine species. It is also found "in saltmarshes in slightly reduced salinities near the mouth of estuaries" (Cabral & Loureiro, 2013). It is common species on most British coasts, rare on the east coast. It appears in outer estuaries from Norway to north Madeira and Canary Islands also (Athersuch et al., 1989).

Genus: *Palmoconcha* Swain & Gilby, 1974

5.2.25. *Palmoconcha laevata* (Norman, 1865)

1865 *Cythere laevata* sp.nov. Norman; Brady: 18, pl.5, fig.13-16.

1981 *Lindisfarnia laevata* (Norman); Horne & Kilenyi: 107-116 (q.v. for more extensive synonymy).

1989 *Palmoconcha laevata* (Norman); Athersuch et al.: 190, fig.76; pl.6, fig.4.

2013 *Palmoconcha laevata* (Norman); Cabral & Loureiro: 145, pl.6, fig.9.

Occurrence: This species was found only in the sediment core (samples TCP 16, TCP 22, TCP 34 and TCP 37) from Two Tree Island. Mostly of the *Palmoconcha laevata* collected from the samples, were juveniles valves. In total only two adult valves were found.

Discussion: *Palmoconcha laevata* is a common marine species in Britain and Iceland, Scandinavia and Atlantic coast of north-west Europe. It lives in littoral algae in rock pools and sublittoral sediment substrates (Athersuch et al., 1989).

Family: PARADOXOSTOMATIDAE Brady & Norman, 1889

Genus: *Cytherois* G. W. Müller, 1884

5.2.26. *Cytherois fischeri* (Sars, 1866)

Plate 9, fig. 12-13

1980 *Cytherois fischeri* (Sars); Horne: 97, pl.18, fig.1-2, fig.5.6(b).

2000 *Cytherois fischeri* (Sars); Horne & Boomer: 197.

2013 *Cytherois fischeri* (Sars); Cabral & Loureiro: 147, pl.7, fig.10.

Occurrence: *Cytherois fischeri* was found at four study sites. The first, at Tollesbury, it appeared in mid and low marsh samples. Among the mid marsh samples (A and AA) mostly adult carapaces were found. Otherwise, one juvenile carapace as well as valves were collected from the low marsh samples (CB and CR). The second location, at Two Tree Island, adult carapaces and juveniles ones were collected from the low marsh surface sample (S 6). In the sediment core, three samples (TCP 13, TCP 16 and TCP 25), contained *C. fischeri*. Here, a mix of adult carapaces and juveniles as well as their valves were found. The third location, on the Isle of Wight, only the northern area contained this species. Mostly found in the lower marsh area (Aas 1 and R 3), adult and juveniles carapaces were collected. The fourth locality, at Gann, it was found in two samples. One surface sample (S 1)

from the low marsh which contained juvenile valves only. And in one sediment core sample (T 4/2), where one juvenile valve was found.

Discussion: *Cytherois fischeri* is a brackish water species which tolerates salinities from 4 to 35 ‰(Cabral & Loureiro, 2013). It lives on sand and filamentous green algae in brackish environments (close to rivers). It is a common species in Britain, and its distribution ranges from south-west France over the Mediterranean to Norway (Athersuch et al., 1989).

5.2.27. *Cytherois* cf. *stephanidesi* Klie, 1938

1938 *Cytherois stephanidesi* Klie: 206-209.

2013 *Cytherois stephanidesi* (Klie); Cabral & Loureiro: 147, pl.7, fig.11.

Occurrence: Only on Isle of Wight was this species found, and only among the mid-high marsh (Mix 1, Mix 2, Mix 4 and Mix 6). A mix of adult and juvenile carapaces together with their valves were collected.

Discussion: *Cytherois stephanidesi* is a brackish-water species which is common among algae and in fine sediment (Horne & Boomer, 2000; Cabral & Loureiro, 2013). This species was found in salinities from 0 to 20 ‰in creeks at Christchurch Harbour in Britain. Other known distributions are the Mediterranean to south-west France (Athersuch et al., 1989).

5.2.28. *Cytherois* sp.

Occurrence: A few representative of the genus *Cytherois* were found in the sediment core (samples TCP 28 and TCP 37) from Two Tree Island, along with *Cytherois fischeri*. Only juvenile carapaces, but mostly valves were collected.

Discussion: Since only juveniles were found, but could not be identified as *Cytherois fischeri*, the specimens were summarised as *Cytherois* sp..

Genus: *Paradoxostoma* Fischer, 1855

5.2.29. *Paradoxostoma ensiforme* Brady, 1868

1980 *Paradoxostoma ensiforme* Brady; Horne: 91, pl.17, fig.12-13, fig.5.11(b).

1989 *Paradoxostoma ensiforme* Brady; Athersuch et al.: 284, fig.122.

1989 *Cytherois stephanidesi* Klie; Athersuch et al.: 312, fig.136.

2013 *Paradoxostoma ensiforme* Brady; Cabral & Loureiro: 147, pl.7, fig.15.

Occurrence: This species was found only in the two deepest sediment core samples (TCP 34 and TCP 37) from Two Tree Island. One adult carapaces plus one valve were found together with a few juvenile valves.

Discussion: *Paradoxostoma ensiforme* is a marine littoral to sublittoral species living on alage and sandy sediment (Athersuch et al., 1989).

5.2.30. *Paradoxostoma trieri* Horne & Whittaker, 1985

Plate 10, fig. 1-2

1989 *Paradoxostoma trieri* Horne & Whittaker; Athersuch et al.: 304, fig.132.

2000 *Paradoxostoma trieri* Horne & Whittaker; Horne & Boomer: 197.

2013 *Paradoxostoma trieri* Horne & Whittaker; Cabral & Loureiro: 147, pl.7, fig.20.

Occurrence: *Paradoxostoma trieri* was collected from the low marsh sample (S 6) as well as one sediment core sample (TCP 34) at Two Tree Island. In the surface sample only adult and juvenile valves were found. The sediment core contained only juvenile valves. At the Isle of Wight it was found alive in the northern sampling area, with its highest abundance in the lower marsh (see table 6.5).

Discussion: “A phytal, littoral marine species, lives in saltmarshes at the limit tidal flat / low marsh [...] It is found on sandy substrate, green and red algae and in an intertidal rock pool” (Cabral & Loureiro, 2013). It is known from Britain and south-west France (Athersuch et al., 1989).

Family: TRACHYLEBERIDIDAE Sylvester-Bradley, 1948

Genus: *Carinocythereis* Ruggieri, 1956

5.2.31. *Carinocythereis* cf. *whitei* (Baird, 1850)

1850 *Cythere whitei* Baird: 364, pl.1-36.

1985 *Carinocythereis whitei* (Baird); Athersuch, Horne & Whittaker:157, pl.2, fig.7-8.

1989 *Carinocythereis whitei* (Baird); Athersuch et al.: 137, fig.54; pl.4, fig.2.

2013 *Carinocythereis whitei* Baird; Cabral & Loureiro: 149, pl.8, fig.11.

Occurrence: Only two juvenile valves of *Carinocythereis* cf. *whitei* were found in the deepest sample (TCP 37) of the sediment core from Two Tree Island.

Discussion: This species is known as a marine sublittoral species which typically lives on sandy or silty substrate.

Genus: *Hiltermannicythere* Bassiouni, 1970

5.2.32. *Hiltermannicythere* cf. *emaciata* (Brady, 1867)

1985 *Hiltermannicythere emaciata* (Brady); Athersuch & Horne: pl.40, fig.1a-3b; pl.42, fig.1a-4b.

1989 *Hiltermannicythere emaciata* (Brady); Athersuch et al.: 144, fig.57; pl.4, fig.5.

2013 *Hiltermannicythere emaciata* (Brady); Cabral & Loureiro: 149, pl.8, fig.16.

Occurrence: This species was collected only from the sediment core (samples TCP 25 and TCP 31 to TCP 37) from Two Tree Island. Only juvenile forms were found, mostly valves.

Discussion: *H. emaciata* is a shallow sublittoral marine species which was found in south England and Iceland (Athersuch et al., 1989).

Family: XESTOLEBERIDIDAE Sars, 1928

Genus: *Xestoleberis* Sars, 1866

5.2.33. *Xestoleberis labiata* Brady & Robertson, 1874

Plate 10, fig. 3

1874 *Xestoleberis labiata* Brady & Robertson: 114-118.

1986 *Xestoleberis labiata* Brady & Robertson; Athersuch & Horne: 51, pl.1 fig.1-4.

1989 *Xestoleberis labiata* Brady & Robertson; Athersuch et al.: 236, fig.100.

2013 *Xestoleberis labiata* Brady & Robertson; Cabral & Loureiro: 149, pl.9, fig.3.

Occurrence: *Xestoleberis labiata*, another rare species, was found only at the northern sampling area on the Isle of Wight. Here, it was found alive mostly in the lower marsh area (R 1, R 3, R 4 and L 1), but a few specimens were also collected from the mid marsh (Aas 1 to Aas 4 and Mix 3). Almost only carapaces were collected, with mostly juveniles from the mid marsh. Whereas, adult and juvenile carapaces were collected from the low marsh.

Discussion: It is known to be a shallow-marine species which prefers sandy substrate, but can also be found among algae and in intertidal rock pools in Portugal (Laje River mouth and lower Mira estuary) (Cabral & Loureiro, 2013). The type locality of this species is New Grimsby Harbour, Scilly Isles (SW England) where it was found among intertidal algae (Athersuch & Horne, 1986). *Xestoleberis labiata* was also found in France, besides the British Isles And now a living British population was discovered in the northern Western Yar Estuary on the Isle of Wight. This species is also known from Scilly to north France and possible the Mediterranean (Athersuch et al., 1989).

5.2.34. *Xestoleberis* sp.

Occurrence: One species of the genus *Xestoleberis* was collected from the sediment core (samples TCP 28 to TCP 37) from Two Tree Island. Mostly juvenile valves, except of one carapace, were found in the samples.

Discussion: Since only juveniles were found, it was only possible to identify the specimens as *Xestoleberis*.

Superfamily: TERRESTRICYTHEROIDEA Schornikov, 1969

Family: TERRESTRICYTHERIDAE Schornikov, 1969

Genus: *Terrestricythere* Schornikov, 1969

5.2.35. *Terrestricythere* cf. *elisabethae* Horne, Smith, Whittaker & Murray, 2004

Plate 10, fig. 4-6

2004 *Terrestricythere elisabethae* sp.nov. Horne, Smith, Whittaker & Murray: 255-275, fig. 1-2, text-fig. 3-17.
2013 *Terrestricythere* aff. *elisabethae* Horne, Smith, Whittaker & Murray; Cabral & Loureiro: 149, pl.9, fig.8-9.

Occurrence: This rare semiterrestrial species was found at two localities: Tollesbury and the Isle of Wight. At the first study site, a living population was discovered to prefer the roots of *Aster tripolium*. This plant could be found growing at mid-high marsh. A few single valves could also be collected from the algae which was growing on *Atriplex*. At the second site, only in the southern sampling area of the Isle of Wight was this species collected. Here, it was also found on the higher marsh surface (sample HL 2) between litter from an oak tree, where it reached it highest abundance. Also in the sediment *Terrestricythere* could be found (sample HL 1).

Discussion: A new species, *Terrestricythere elisabethae* was found in and described from semiterrestrial coastal habitat at sites in Hampshire, S England (Horne et al., 2004). Therefore, it was assumed that the collected *Terrestricythere* also belongs to the same species. So far no soft parts were examined, and the observations about the species were made based on the morphology and the present literature.

Plate 6

Fig. 1-4: *Cyprideis torosa*

1: juvenile valve (A4), right valve, external, 160x, Tollesbury (T II AA 1).

2: adult carapace (female), external, 100x, Tollesbury (T XII SP 4).

3: adult carapace (female?), external, 100x, Two Tree Island (TTI TCP 13).

4: adult carapace (male?), external, 100x, Two Tree Island (TTI Aas 2).

Fig. 5-8: *Hemicythere rubida*

5: adult valve (female), left valve, external, 160x, Isle of Wight (IW north).

6: adult carapace (female), external, 160x, Isle of Wight (IW south).

7: adult valve (male), left valve, external, 190x, Tollesbury (T V A 17).

8: adult valve (female), left valve, internal, 160x, Isle of Wight (IW north).

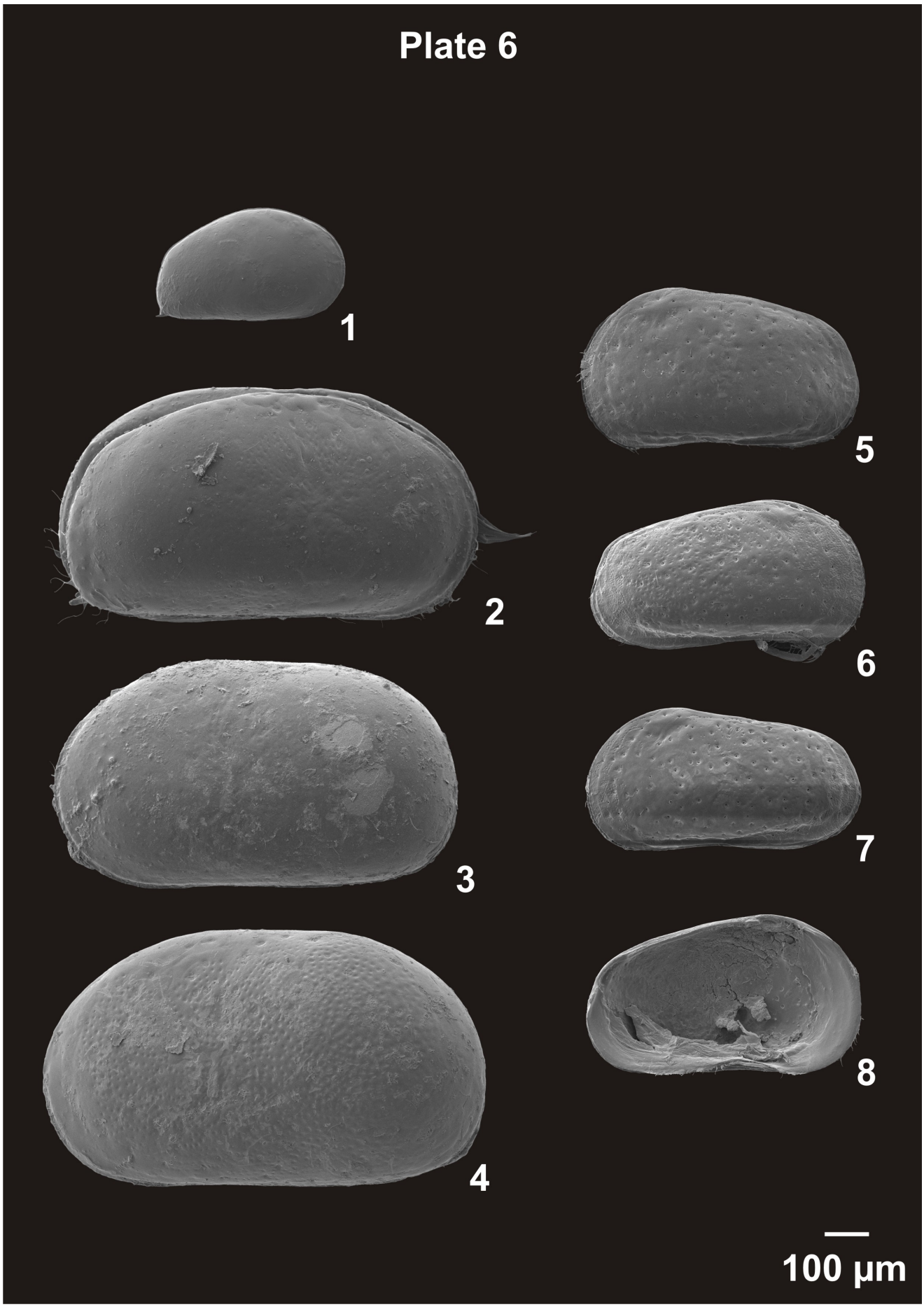
Plate 6
1
2
3
4
5
6
7
8
100 µm

Plate 7

Fig. 1-8: *Leptocythere castanea*

1: adult valve (male), right valve, external, 160x, Gann (G S 1).

2: adult carapace (male), external, 160x, Isle of Wight (IW north).

3: adult valve (male), left valve, external, 160x, Isle of Wight (IW north).

4: adult carapace (male), external, 190x, Two Tree Island (TTI TCP 13).

5: adult carapace (female), external, 190x, Two Tree Island (TTI TCP 13).

6: adult valve (female), right valve, external, 160x, Isle of Wight (IW north).

7: adult valve (female), right valve, internal, 160x, Isle of Wight (IW north).

8: adult valve (female), right valve, internal, 160x, Isle of Wight (IW north).

Fig. 9-11: *Leptocythere ciliata*

9: adult carapace (female), external, 190x, Gann (G S1).

10: adult carapace (female), external, 190x, Tollesbury (T III A 3).

11: adult valve (female), left valve, broken, external, 190x, Tollesbury (T IV A 12).

Fig. 12-14: *Leptocythere fabaeformis*

12: adult carapace (male), external, 100x, Isle of Wight (IW north).

13: adult carapace (female), external, 160x, Isle of Wight (IW north).

14: adult valve (male), left valve, internal, 100x, Isle of Wight (IW north).

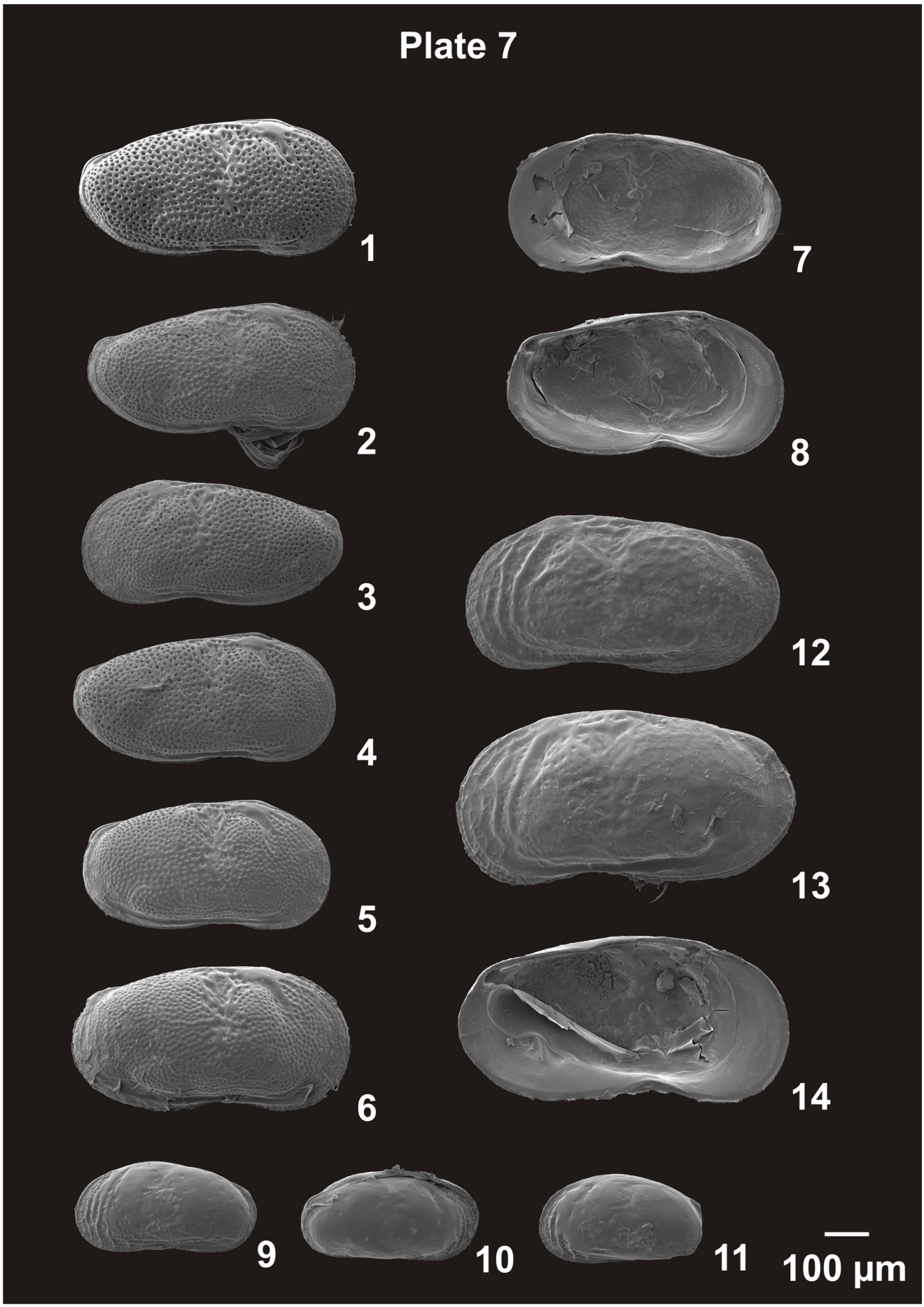
Plate 7
1
2
3
4
5
6
7
8
12
13
14
9
10
11
100 µm

Plate 8

Fig. 1-6: *Leptocythere porcellanea*

1: adult carapace (female), external, 190x, Gann (G S 1).

2: adult carapace (female), external, 190x, Gann (G S 1).

3: adult carapace (female), external, 160x, Isle of Wight (IW north).

4: adult carapace (male), external, 190x, Two Tree Island (TTI TCP 13).

5: juvenile carapace (A1, female), external, 190x, Tollesbury (T III A 3).

6: adult carapace (female), external, 190x, Tollesbury (T V A 13).

Fig. 7-14: *Loxoconcha elliptica*

7: adult carapace (female), external, 160x, Gann (G S 1).

8: adult carapace (male), external, 170x, Gann (G S 1).

9: juvenile carapace (A1, female), external, 190x, Gann (G S 1).

10: juvenile valve (A2), left valve, external, 160x, Gann (G S 1).

11: juvenile valve (A3), left valve, external, 160x, Gann (G S 1).

12: juvenile carapace (A4), external, 190x, Gann (G S 1).

13: adult carapace (male), external, 160x, Two Tree Island (TTI TCP 25).

14: juvenile carapace (A1, female), external, 190x, Two Tree Island (TTI TCP 25).

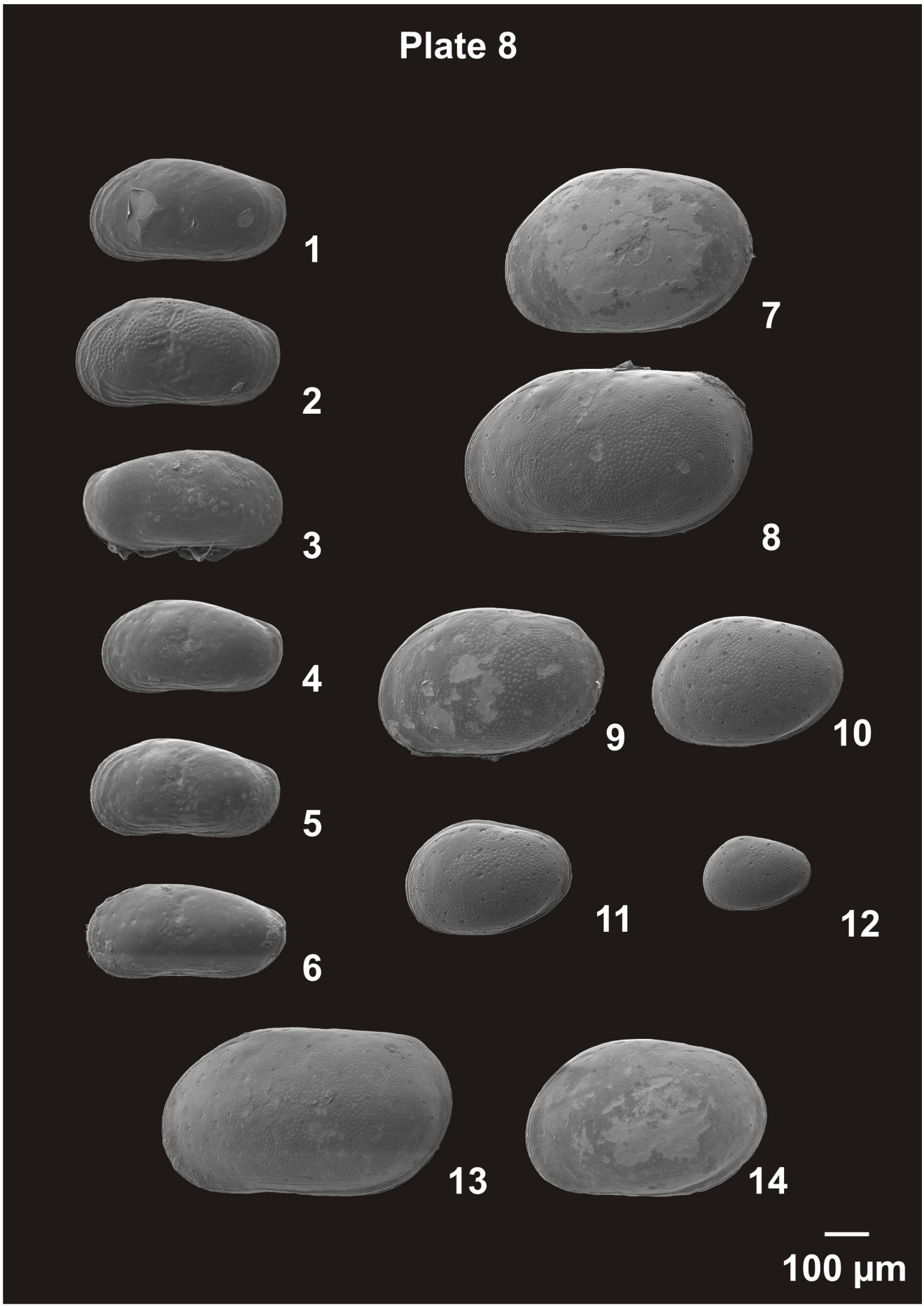
Plate 8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
100 µm

Plate 9

Fig. 1-8: *Loxoconcha malcomsoni*

1: adult valve (male), right valve, external, 190x, Tollesbury (T IV A 8).

2: adult carapace (female), external, 190x, Tollesbury (T IV A 8).

3: adult carapace (male), external, 190x, Tollesbury (T VI A 18).

4: adult valve (female), right valve, external, 190x, Tollesbury (T VI A 18).

5: adult carapace (female), external, 190x, Tollesbury (T V A 13).

6: adult valve (male), right valve, internal, 190x, Tollesbury (T IV A 8).

7: adult valve (female), right valve, internal, 190x, Tollesbury (T VI A 18).

8: adult carapace (female), hinge view, external, 160x, Tollesbury (T IV A 8).

9: adult valve (female), left valve, teeth, internal, 330x, Tollesbury (T VI A 18).

10: adult valve (female), left valve, muscle scars, internal, 850x, Tollesbury (T VI A 18).

Fig. 11: *Loxoconcha rhomboidea*

11: adult carapace (female), external, 160x, Isle of Wight (IW north).

Fig. 12-13: *Cytherois fischeri*

12: adult carapace (female), external, 190x, Isle of Wight (IW north).

13: adult carapace (male), external, 190x, Two Tree Island (TTI S 6).

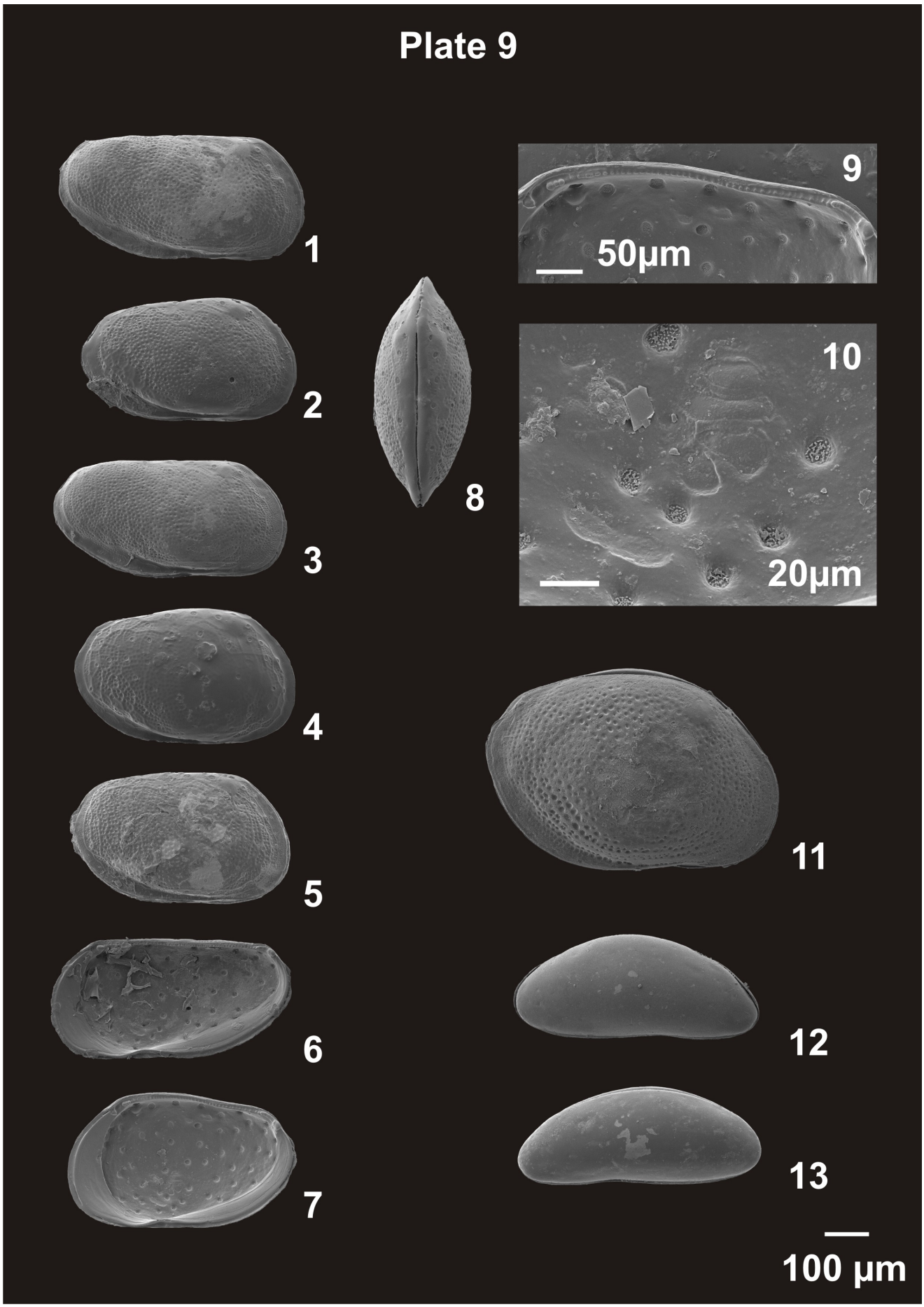
Plate 9
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8
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50µm
10
20µm
11
12
13
100 µm

Plate 10

Fig. 1-2: *Paradoxostoma trieri*

1: adult carapace (male), external, 160x, Isle of Wight (IW north).

2: juvenile carapace (A1, female), external, 190x, Two Tree Island (TTI S 6).

Fig. 3: *Xestoleberis labiata*

3: adult carapace (male), external, 190x, Isle of Wight (IW north).

Fig. 4-6: *Terrestricythere* cf. *elisabethae*

4: adult carapace (male), external, 190x, Tollesbury (T VI Terr).

5: adult carapace (male), hinge view, external, 100x, Isle of Wight (IW south).

6: adult valve (female), left valve internal, 190x, Isle of Wight (IW south).

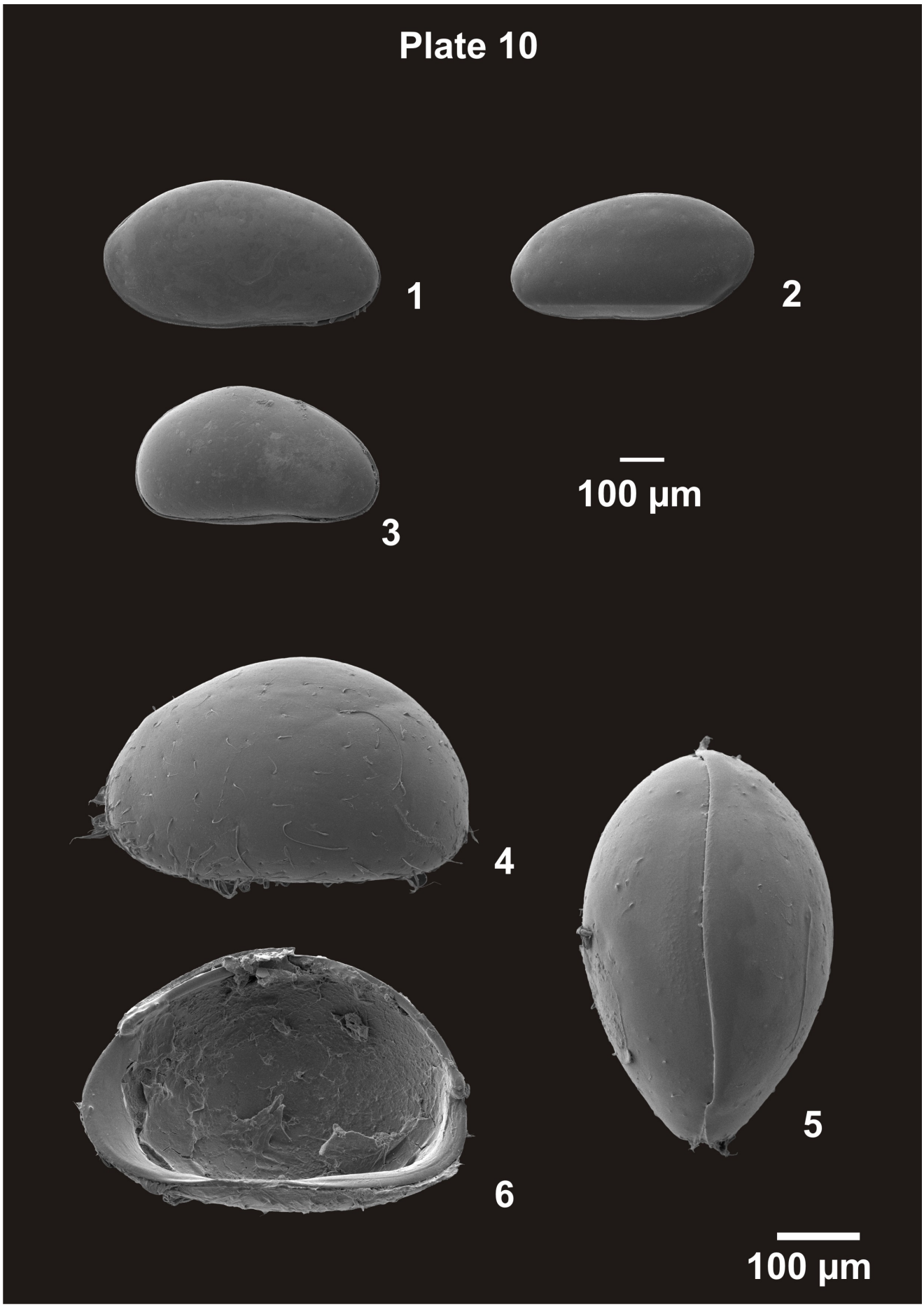
Plate 10
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100 µm
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6
100 µm

6. Results and Discussion

The results chapter lists all analysed data, ranging from GPS and elevation data of saltmarsh surface and samples, over Foraminifera and Ostracoda assemblages from sediment core and surface samples. The latter also includes a seasonal study from the Tollesbury saltmarsh as well as an Ostracoda analysis regarding rare species from the Isle of Wight. Besides microfossils, also particle size analysis (PSA) from several sediment cores was conducted. In total, 244 saltmarsh samples containing 8 196 Ostracoda and 58 601 Foraminifera were analysed.

6.1. GPS and elevation data

From the Tollesbury study site, GPS and elevation data from the marsh surface as well as its plant zonation (*Elytrigia*, *Puccinellia*, *Atriplex*, *Salicornia*) were measured. Furthermore, most surface and sediment core locations were also measured within the tide regime, using the Admiralty Tide Table (ATT) to convert the elevation data (in metre) from Ordinance Datum (O.D.) into Chart Datum (C.D.) (Admiralty Tide Tables, 1977). With a hand-held GPS and imagine station, positions and elevations, were measured, see chapter 2.6 about methods. All sample locations and elevation data can be found in appendix C.

6.1.1. Saltmarsh surface elevation data from Tollesbury

Three transects (A, B and C) were undertaken at the Tollesbury saltmarsh study site, covering the inner as well as the outer marsh area. The measured data of each one describes the elevation data from the marsh as well as the creek surface. These elevation data reflect the slope of the saltmarsh plateau and its creeks towards the Tollesbury Fleet. All transects were taken east of the managed realignment site (MRS) in the adjacent old saltmarsh. Elevation data in Chart Datum (C.D.) were calculated from the tides measured at West Mersea (MHWST = 5.10 m and MHWNT = 3.80 m), which were found in the ATT (Admiralty Tide Tables, 1977).

Transect A (figure 6.1) is over 100 m long, runs nearly parallel to the sea wall, which separates the marsh from the hinterland, and covers the inner saltmarsh area. The measured points are A 1 to A 16 and consist of eight marsh as well as eight creek surface points. The highest marsh surface reached 5.38 m C.D. (A 2) and the lowest 5.18 m C.D. (A 8), with a mean value of 5.29 m C.D. of all 8 measured points. The highest creek surface reached

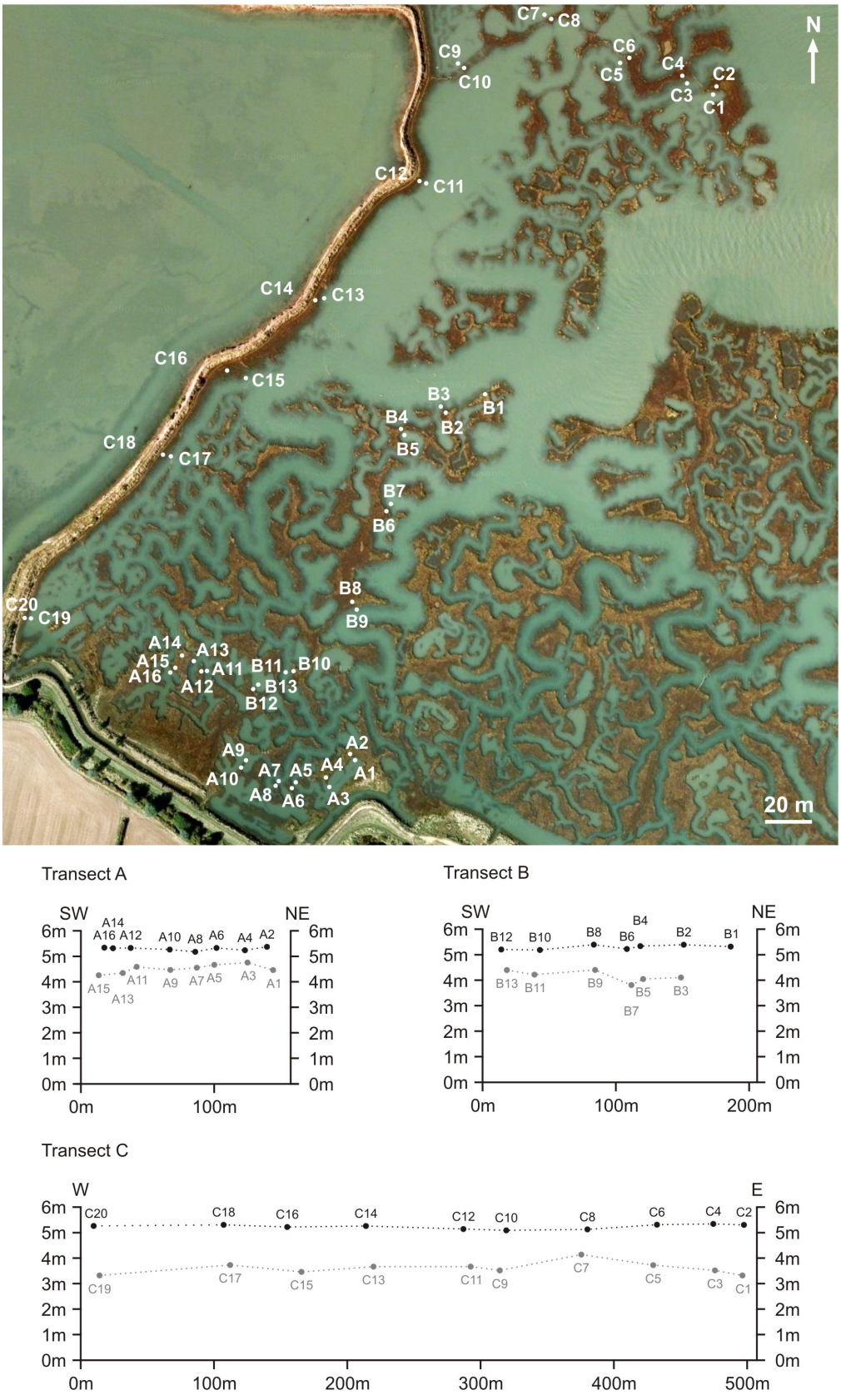

Figure 6.1.: Tollesbury saltmarsh transects (A, B and C) representing elevation data from marsh surface and creeks. Elevation data (y axis) are given in Chart Datum (C.D.), whereas the x axis shows the distance in 100 m steps. The C.D. is calculated from the tides measured at West Mersea (MHWST = 5.10 m and MHWNT = 3.80 m), found in the ATT (Admiralty Tide Tables, 1977). All data are found in appendix C, table C.2.

4.76 m C.D. (A 3) and the lowest 4.37 m C.D. (A 13), with a mean value of 4.54 m of all 8 measured elevation points.

Transect B is over 200 m long, runs perpendicular to the sea wall and covers the inner and middle marsh area. The measured points range from B 1 to B 13 and include seven marsh as well as six creek surface data, see figure 6.1. The highest marsh surface reached 5.40 m C.D. (B 8) and the lowest 5.21 m C.D. (B 12), with a mean value of 5.29 m C.D. of all 7 measured points. The highest creek surface reached 4.40 m C.D. (B 13) and the lowest 3.91 m C.D. (B 7), with a mean value of 4.17 m of all 6 measured elevation points.

Transect C is over 500 m long, runs mostly parallel to the sea wall, separating the MRS from the adjacent old marsh, and covers the inner and outer marsh area. The measured data range from C 1 to C 20 and consist of ten marsh as well as ten creeks surface points, see figure 6.1. The highest marsh surface reached 5.34 m C.D. (C 4) and the lowest 5.09 m C.D. (C 6), with a mean value of 5.26 m C.D. of all 10 measured points. The highest creek surface reached 4.34 m C.D. (C 1 and C 19) and the lowest 3.46 m C.D. (C 15), with a mean value of 3.80 m of all 10 measured elevation points.

Discussion of transects

At the Tollesbury saltmarsh site, three surface transects were sampled. One ran parallel to the sea wall (transect A), one covered the inner and middle marsh area (transect B) and the last one, which was the longest, extended from the inner to the outer marsh area (transect C). Points were measured one from the marsh surface as well as the adjacent creek. The first transect showed only a difference of 0.12 cm between its highest and lowest marsh surface point, and for the creek surface a difference of 0.22 cm was measured compared to the highest and lowest points. Transect B shows a 0.19 cm height difference between its highest and lowest marsh surface, and a 0.49 cm height difference for the creek surface. Transect C contained a height difference between its lowest and highest marsh point of 0.25 cm, and for the creek surface the height difference was with 0.86 cm the highest one from all transects. Overall, the plateau marsh surface did not show a significant drop of its surface towards the marsh edge. Plateau like saltmarshes were also common at other study sites (chapter 3.2), where the pioneer zone only exists on slumped sediment block at the creek edges or marsh cliff this was also the case at Tollesbury saltmarsh.

6.1.2. Saltmarsh plant zone elevation data from Tollesbury

From the Tollesbury saltmarsh, plant species zones were measured from the inner to outer marsh area. The chosen plant species were *Elytrigia*, *Puccinellia*, *Atriplex* and *Salicornia*, the most common plant species at this site. With a GPS, the elevation data of each zone were measured to record their boundaries and to detect irregularities of plant zonations if present. This was done, because Foraminiferal assemblages reflect marsh zones, which are defined visible through different plant species on a marsh surface, and irregular patterns in plant zones might

affect the spacial distribution of them. Therefore, upper and lower elevations of each plant zone were measured, using *Elytrigia* and *Puccinellia* as high marsh, *Atriplex* as mid marsh and *Salicornia* as low marsh indicators, with the creek bottom as the lowest limit. All data were measured east of the MRS in the adjacent old saltmarsh. Elevation data in Chart Datum (C.D.) were calculated from the tides measured at West Mersea (MHWST = 5.10 m and MHWNT = 3.80 m), which were found in the ATT (Admiralty Tide Tables, 1977).

The inner marsh plant zones consist of four zones: E 1 (*Elytrigia*), P 1 (*Puccinellia*), A 1 (*Atriplex*) and S 1 (*Salicornia*). The middle marsh plant zones consist of three zones: P 2 (*Puccinellia*), A 2 (*Atriplex*) and S 2 (*Salicornia*). And the only plant zone measured from the outer marsh was A 3 (*Atriplex*), because *Atriplex* was dominating this marsh area. The plant zone E 1 (*Elytrigia*) could only be measured from the inner marsh, because *Elytrigia* was not present at the middle or outer marsh area. And for the plant zone P 1 and P 2 (*Puccinellia*), no clear boundaries could be measured due to its intermixing with other plant species. However it was tired to be measured nonetheless, since it represented the only high-mid marsh plant in the middle marsh area.

The four plant zones (E 1, P 1, A 1 and S 1) measured from the inner marsh run parallel to the sea wall, which separates the old saltmarsh from the hinterland, see figure 6.2. The highest marsh zone E 1 was measured here with *Elytrigia* and consist of eight upper (E1 U1 to E1 U8) and nine lower (E1 L1 to E1 L9) boundary elevation points. The highest elevation of the upper boundary was at 6.12 m C.D. (E1 U8) and the lowest at 5.27 m C.D. (E1 U2), with a mean value of 5.57 m for all 8 elevation measurements. The highest elevation of the lower boundary was at 5.37 m C.D. (E1 L8) and the lowest at 5.22 m C.D. (E1 L4), with a mean value of 5.29 m for all 9 elevation measurements. The high-mid marsh zone P 1 was measured with *Puccinellia* and consist of ten elevation points (P1 M1 to P1 M10). The highest elevation point was measured at 5.19 m C.D. (P1 M8 and P1 M10) and the lowest at 4.87 m C.D. (P1 M7), with a mean value of 5.06 m for all 10 elevation measurements. The mid marsh zone A 1 was measured with *Atriplex* and consist of ten upper (A1 U1 to A1 U10) and ten lower (A1 L1 to A1 L10) elevation boundary measurements. The highest elevation of the upper boundary was at 5.25 m C.D. (A1 U1) and the lowest 4.89 m C.D. (A1 U4), with a mean value of 5.12 m for all 10 elevation measurements. The highest elevation of the lower boundary was at 5.22 m C.D. (A1 L4) and the lowest at 4.60 m C.D. (A1 L4), with a mean value of 4.80 m for all 10 elevation measurements. The lower marsh zones S 1 was measured with *Salicornia* and consist of six upper (S1 U1 to S1 U6) and six lower (S1 L1 to S1 L6) boundary elevation points. The highest elevation of the upper boundary was at 5.09 m C.D. (S1 U5) and the lowest 4.83 m C.D. (S1 U4), with a mean value of 4.59 m for all 6 elevation measurements. The highest elevation of the lower boundary was at 5.51 m C.D. (S1 L3) and the lowest at 4.07 m C.D. (S1 L1), with a mean value of 4.23 m for all 6 elevation measurements.

The three plant zones (P 2, A 2 and S 2) from the middle marsh were measured vertical to the sea wall, see figure 6.3. The highest marsh zone P 2 was measured with *Puccinellia* (high-mid marsh) and consist of eight

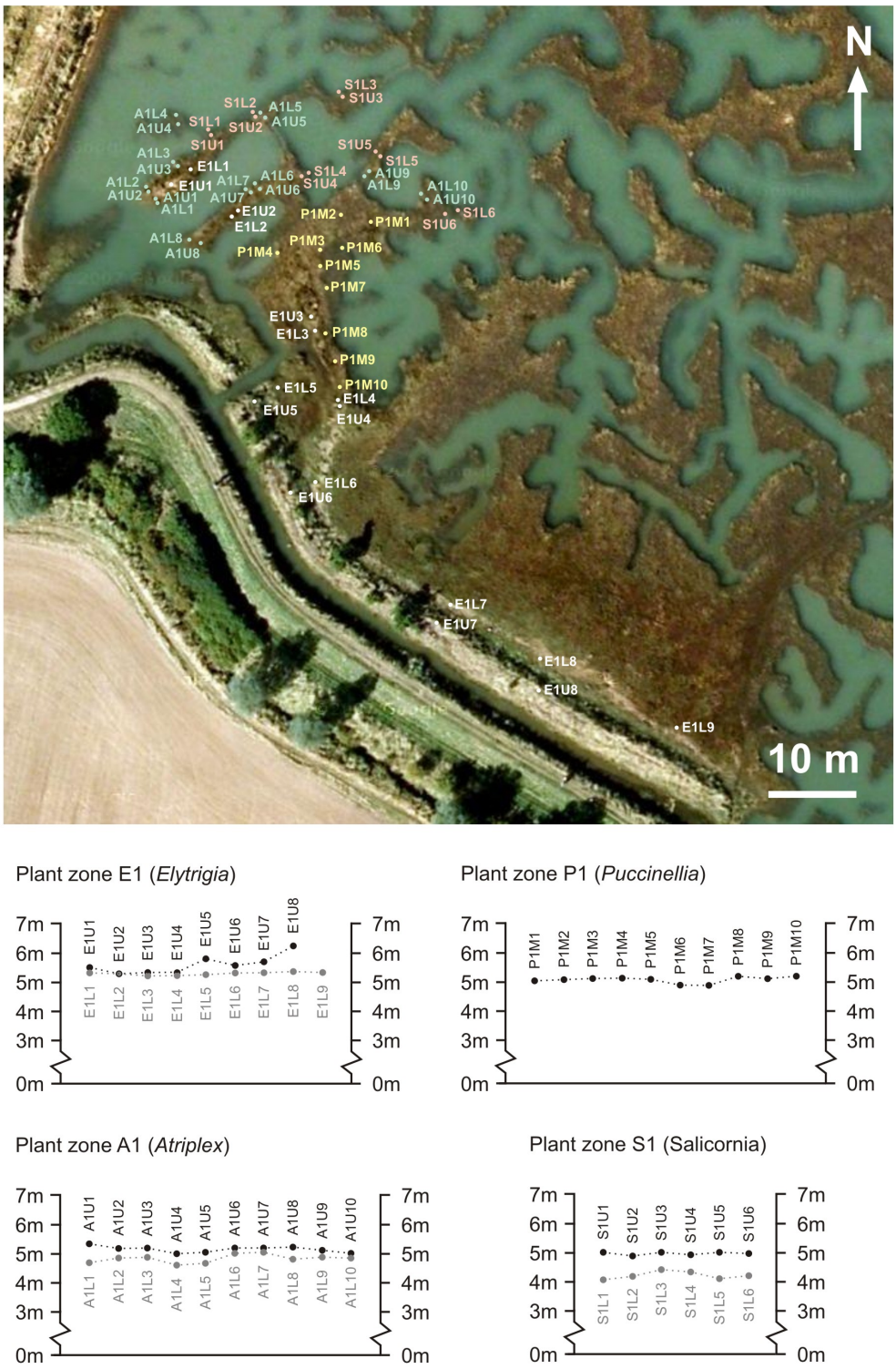

Figure 6.2.: Tollesbury inner saltmarsh plant zones with their elevation boundaries. Elevation data (y axis) are given in Chart Datum (C.D.), whereas the x axis is unscaled. The C.D. is calculated from the tides measured at West Mersea (MHWST = 5.10 m and MHWNT = 3.80 m), found in the ATT (Admiralty Tide Tables, 1977). Four plant zones were measured: E 1 = *Elytrigia* (high), P 1 = *Puccinellia* (high-mid), A 1 = *Atriplex* (mid) and S 1 = *Salicornia* (low marsh), where U stands for upper (black) and L for lower (grey) boundary, except for *Puccinellia*. This plant species was inter-grown with other species, so no boundaries were visible (M = middle). All data are found in appendix C, table C.3.

elevation points (P2 M1 to P2 M8). The highest elevation point was measured at 5.02 m C.D. (P2 M1 and P2 M3) and the lowest at 4.91 m C.D. (P2 M8), with a mean value of 4.97 m for all 8 elevation measurements. The mid marsh zone was measured with *Atriplex* and consist of eight upper (A2 U1 to A2 U8) and eight lower (A2 L1 to A2 L8) elevation boundary points. The highest elevation of the upper boundary was at 5.16 m C.D. (A2 U7) and the lowest 4.95 m C.D. (A2 U4), with a mean value of 5.05 m for all 8 elevation measurements. The highest elevation of the lower boundary was at 5.06 m C.D. (A2 L8) and the lowest at 4.65 m C.D. (A2 L4), with a mean value of 4.86 m for all 8 elevation measurements. The lower marsh zone S 2 was measured with *Salicornia* and consist of eight upper (S2 U1 to S2 U8) and eight lower (S2 L1 to S2 L8) boundary elevation points. The highest elevation of the upper boundary was at 5.00 m C.D. (S2 U8) and the lowest 4.72 m C.D. (S2 U7), with a mean value of 4.90 m for all 8 elevation points. The highest elevation of the lower boundary was at 4.39 m C.D. (S2 L8) and the lowest at 3.78 m C.D. (S2 L7), with a mean value of 4.05 m for all 8 elevation measurements.

The only plant zone (A 3) was measured from the outer marsh area, see figure 6.3. The mid marsh zones, which dominated this area, was measured with *Atriplex* and consist of five upper (A3 U1 to A3 U5) and five lower (A3 L1 to A3 L5) elevation boundary points. The highest elevation of the upper boundary was at 5.23 m C.D. (A3 U4) and the lowest 5.09 m C.D. (A3 U1), with a mean value of 5.14 m for all 5 elevation measurements. The highest elevation of the lower boundary was at 5.01 m C.D. (A3 L4) and the lowest at 4.86 m C.D. (A3 L3), with a mean value of 4.92 m for all 5 elevation measurements.

Discussion of plant zones

Furthermore, from the main study site (Tollesbury), the elevations of the upper and lower boundaries between each plant zone were also measured (chapter 6.1.2). This was done, to test if the present marsh zones show a distinct boundary or not, by measuring distributions of *Elytrigia* (high marsh), *Atriplex* (mid marsh) and *Salicornia* (low marsh). The results for the inner marsh plant zones revealed that the high marsh plant *Elytrigia* grows between 5.5 m and 5.2 m C.D.. The mid marsh plant zone *Atriplex* appears from 5.1 m to 4.8 m C.D., and the low marsh plant zone *Salicornia* stays between 4.9 m and 4.2 m C.D.. Only *Puccinellia* showed no clear boundary, instead it was inter-growing with *Elytrigia* and *Atriplex* (5.0 cm C.D.). For the middle marsh area *Atriplex* occurs between 5.0 m and 4.8 m C.D. and *Salicornia* stayed between 3.9 m and 3.2 m C.D.. Also, *Puccinellia* mixes here with *Atriplex* only (4.9 cm C.D.). At the outer marsh, the upper and lower plant zone boundaries of *Atriplex* stayed the same as before, with 5.1 m and 4.9 m C.D.. Normally the marsh zone boundaries are influenced either by interspecific competition or through physico-chemical changes (Olff et al., 1997; Davy, 2000). Given that each marsh zone showed such clear distinctions, it was possible to conduct a seasonal study on Foraminifera and Ostracoda for all three marsh zones (high, mid and low).

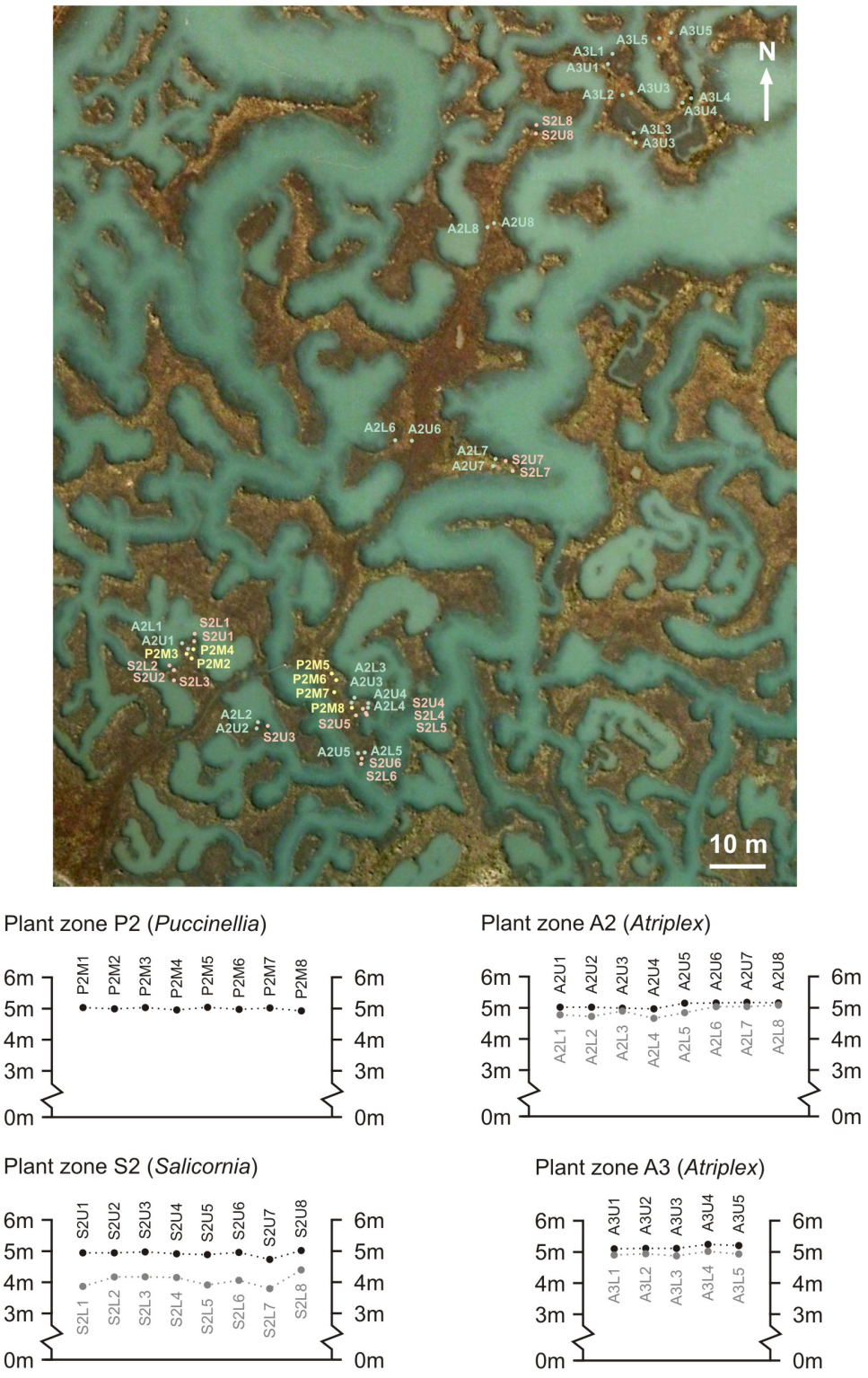

Figure 6.3.: Tollesbury middle and outer saltmarsh plant zones with their elevation boundaries. Elevation data (y axis) are given in Chart Datum (C.D.), whereas the x axis is unscaled. The C.D. is calculated from the tides measured at West Mersea (MHWST = 5.10 m and MHWNT = 3.80 m), found in the ATT (Admiralty Tide Tables, 1977). Three plant zones were measured: P 2 = *Puccinellia* (high-mid), A 2 = *Atriplex* (mid) and S 2 = *Salicornia* (low marsh), where U stands for upper (black) and L for lower (grey) boundary, except for *Puccinellia*. This plant species was inter-grown with other species, so no boundaries were visible (M = middle). The only plant zone measured from the outer marsh was A 3 = *Atriplex*. All data are found in appendix C, table C.3.

6.1.3. Saltmarsh sample GPS and elevation data

From 11 study sites, location and elevation data for surface samples and sediment cores were measured: Tollesbury, Grange-over-Sands, Roudsea Woods, Drumburgh, Nith, Cree, Arrochar, Loch Riddon, Kyleakin, Loch Ainort and Loch Sligachan. A map showing an overview of each measured location (samples) for each study site can be found in chapter 3.2. Using the Admiralty Tide Table (ATT), these data were converted from Ordinance Datum (O.D.) to Chart Datum (C.D.) (Admiralty Tide Tables, 1977) to estimate their location within the tidal regime.

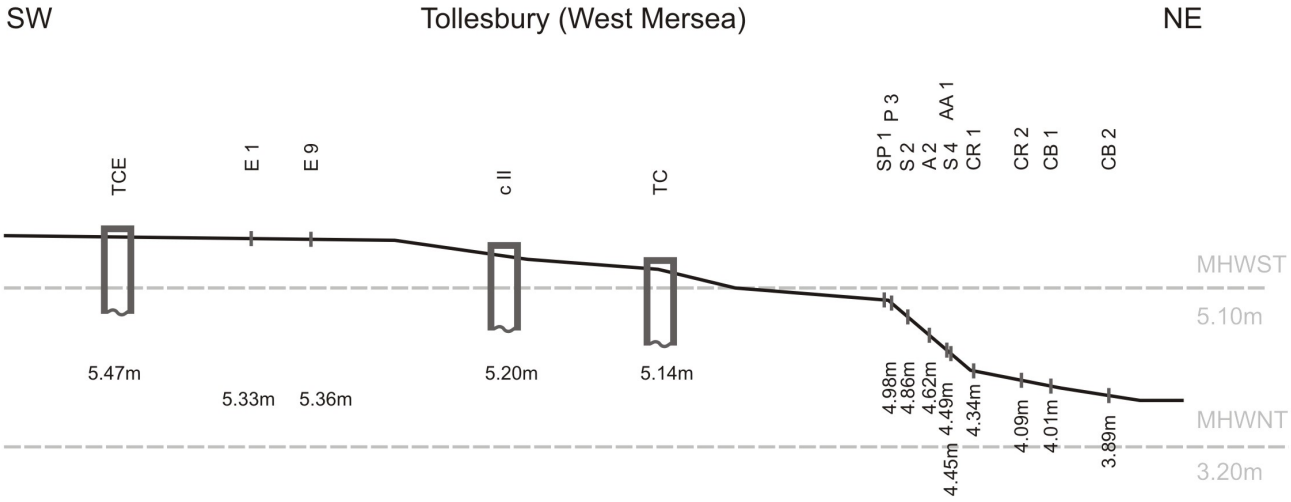

Figure 6.4.: Sketch showing a Tollesbury saltmarsh transect indicating its surface (black line) with elevation data in metres C.D. which were calculated from the tides measured at West Mersea (MHWST = 5.10 m and MHWNT = 3.80 m, dotted grey lines) (Admiralty Tide Tables, 1977). Also, three sediment cores (TCE, cII, TC) are indicated as cylinders. The arrangement of the samples and cores in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

For the Tollesbury saltmarsh, the location and elevation of 12 surface samples (E 1, E 9, P 3, A 2, AA 1, S 2, S 4, SP 1, CB 1, CB 2, CR 1, CR 2) and three sediment cores (TCE, cII, TC) were measured, see figure 3.2. The samples with their elevation given in Chart Datum (C.D.) were calculated from the tides measured at West Mersea (MHWST = 5.10 m and MHWNT = 3.80 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.4. The highest surface sample was measured with an elevation of 5.33 m C.D. (E 1) and the lowest at 3.89 m C.D. (CB 2). No samples were measured below the MHWNT level. All sediment cores were extracted above the MHWST level.

From the Grange-over-Sands saltmarsh, the location and elevation of three surface samples (Ph, Pl, MF) and one sediment core (C) were measured, see figure 3.12. The elevations of the samples were calculated in C.D. from the tides measured at Barrow Docks (MHWST = 9.14 m and MHWNT = 7.07 m), extracted from the ATT

(Admiralty Tide Tables, 1977), see figure 6.5. The highest surface sample was measured at 9.86 m C.D (Ph) and the lowest at 8.77 m C.D. (Pl), but none were measured below the MHWNT level. The sediment core was extracted above the MHWST level, at 9.73 m C.D..

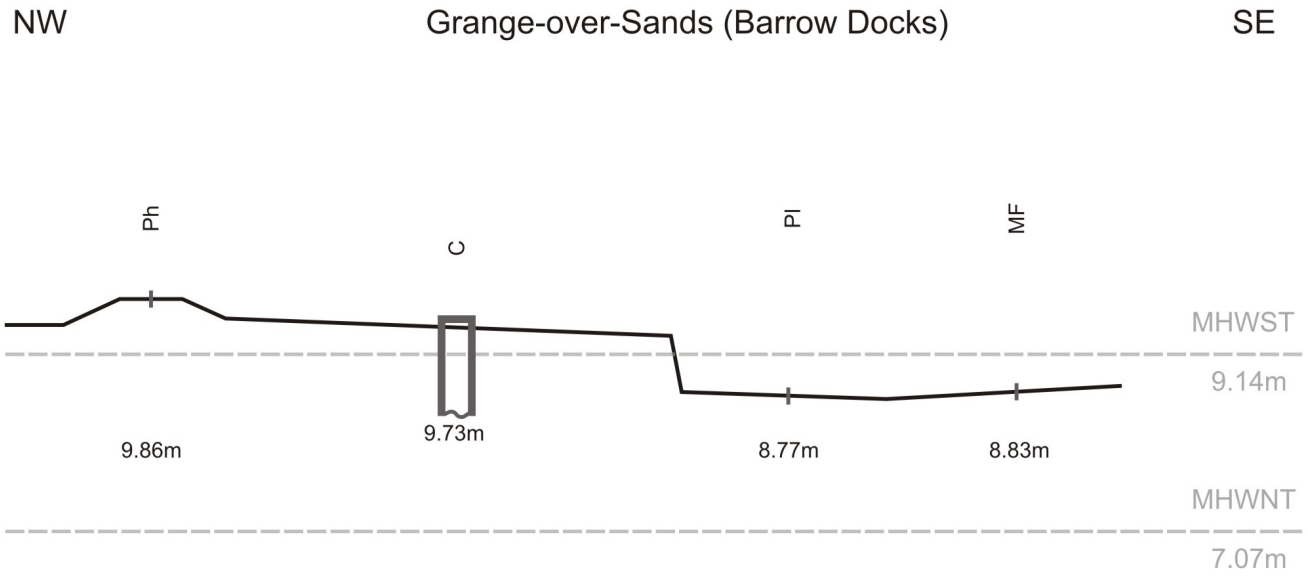

Figure 6.5.: A sketch of a transect from the Grange-over-Sands saltmarsh showing its surface (black line) with elevation data in metres C.D., which were calculated from the tides measured at Barrow Docks (MHWST = 9.14 m and MHWNT = 7.07 m, dotted grey lines) (Admiralty Tide Tables, 1977). One sediment core (C) is indicated as a cylinder. The arrangement of the samples and the core in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide levels.

The Roudsea Woods saltmarsh location and elevation of four surface samples (E, P, LM, MF) and one sediment core (C) were measured, see figure 3.14. The samples' elevations as C.D.) were calculated from the tides measured at Heysham (MHWST = 9.48 m and MHWNT = 7.44 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.6. The highest surface sample was measured at 9.83 m C.D (E) and the lowest at 8.30 m C.D. (MF), but none were measured below the MHWNT level. The sediment core was extracted above the MHWST level, at 9.53 m C.D..

The location and elevation of one saltmarsh surface sample (MF), three terraces (TH, TM, TL) and three marsh sediment cores (c I, c II, c III) were measured from the Drumburgh site, see figure 3.16. The samples with their elevation represented in C.D. were calculated from the tides measured at Newbie (MHWST = 7.10 m and MHWNT = 4.75 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.7. The only surface sample was measured at an elevation of 5.35 m C.D (MF). The highest terrace was measured with an elevation at 7.82 m C.D. (TH), the middle terrace at 7.20 m C.D. (TM) and the lowest at 6.00 m C.D. (TL). No surface

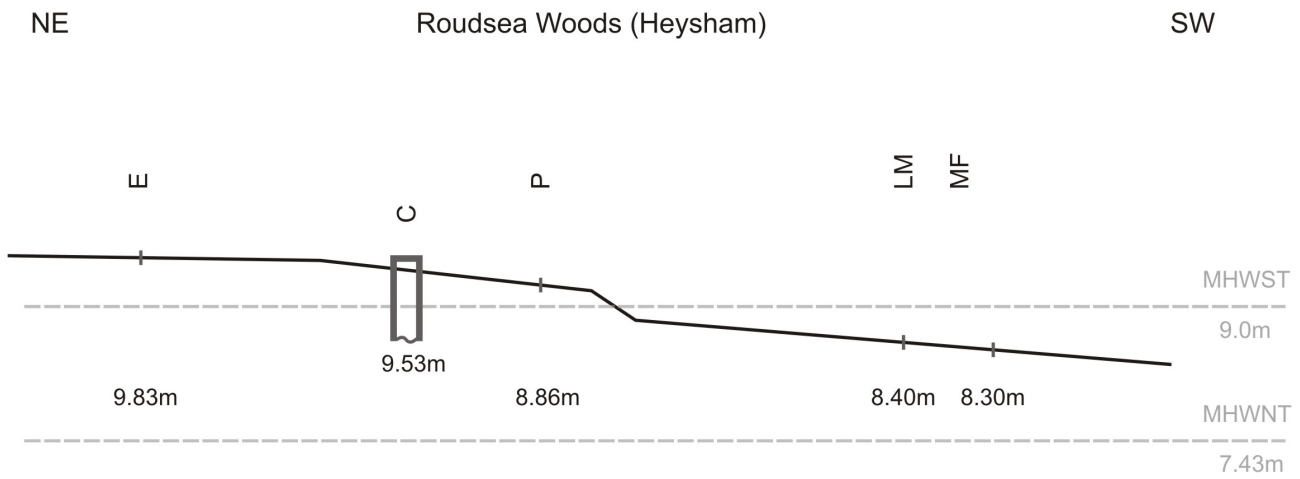

Figure 6.6.: Transect of the marsh surface (black line) of the Roudsea Woods study site indicating elevation data in metres C.D. that were calculated from the tides measured at Heysham (MHWST = 9.48 m and MHWNT = 7.44 m, dotted grey lines) (Admiralty Tide Tables, 1977). One sediment core (C) is indicated as a cylinder. The arrangement of the samples and the core in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

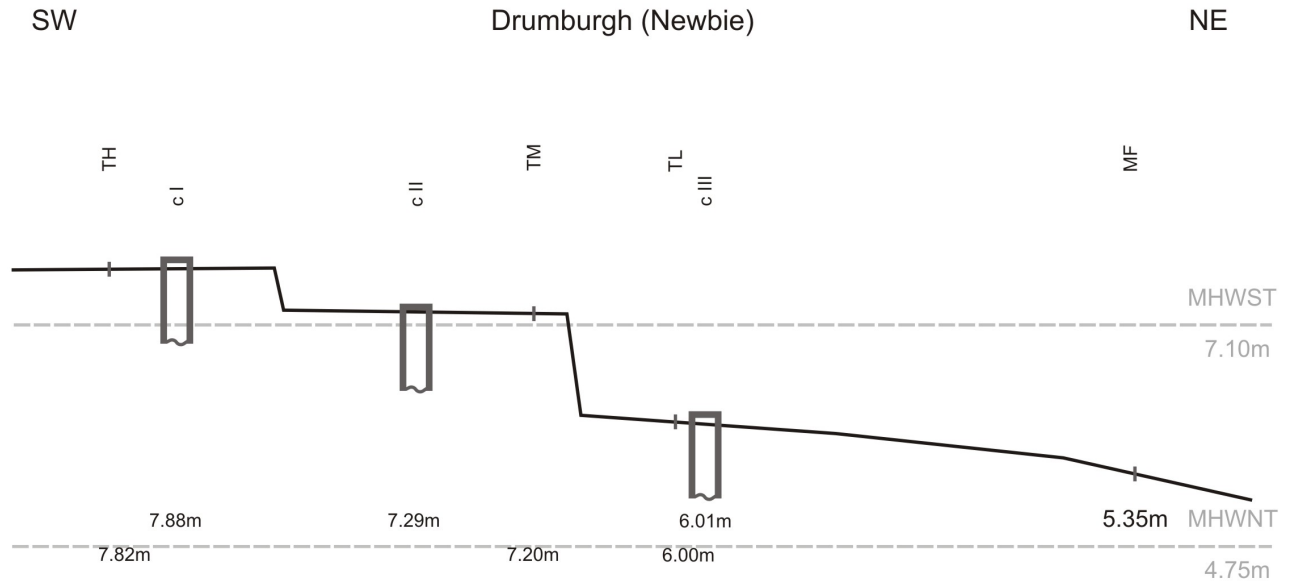

Figure 6.7.: Sketch of a Drumburgh saltmarsh transect showing its surface (black line) with elevation data in metres C.D. which were calculated from the tides measured at Newbie (MHWST = 7.10 m and MHWNT = 4.75 m, dotted grey lines) (Admiralty Tide Tables, 1977). The sediment cores (c I, c II, c III) are indicated as cylinders. The arrangement of the samples and cores in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

measurements were below the MHWNT level. Two sediment cores (c I, c II) were extracted above the MHWST level at 7.88 m C.D. and 7.29 m C.D., and one core below it (c III) at 6.01 m C.D..

For the Nith saltmarsh, the location and elevation of one surface sample (MF), two terraces (TH, TL) and two sediment cores (c I, c II) were measured, see figure 3.18. The elevations of the samples were calculated as C.D., from the tides measured at Hestan Islet (MHWST = 8.29 m and MHWNT = 6.31 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.8. The elevation of the surface sample was measured at 7.69 m C.D (MF) and the terraces at 9.22 m C.D. (TH) and at 8.81 m at (TL), both of them above the MHWST level. No surface sample was measured below MHWNT level. The two sediment cores were measured at 9.29 m C.D. (c I) and at 8.12 m C.D. (c II) elevation.

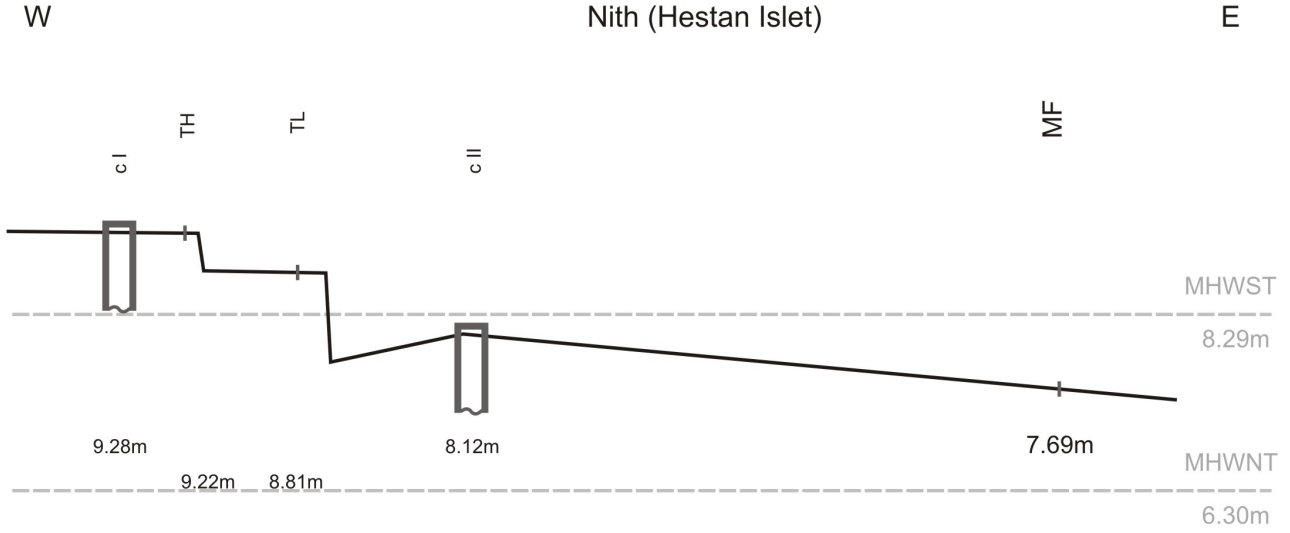

Figure 6.8.: Nith saltmarsh transect sketch with its surface (black line) and elevation data (C.D.), calculated from the tides measured at Hestan Islet (MHWST = 8.29 m and MHWNT = 6.31 m, dotted grey lines) (Admiralty Tide Tables, 1977). The sediment cores (c I, c II) are indicated as cylinders. The arrangement of the samples and cores in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

The Cree saltmarsh location and elevation of one surface sample (MF), two surface points (sH, sc I) and two sediment cores (c I, c II) were measured, see figure 3.20. The samples with their elevation given in C.D. were calculated from the tides measured at Kirkcudbright Bay (MHWST = 7.50 m and MHWNT = 5.94 m), which were extracted from the ATT (Admiralty Tide Tables, 1977), see figure 6.9. The elevation of the surface sample was measured at 5.63 m C.D (MF). Also two more surface points were measured at 6.81 m C.D. (sH) and at 6.70 m at (sc I), above the MHWST level, no surface sample was below the MHWNT level. The two sediment cores were measured at 6.72 m C.D. (c I) and at 5.68 m C.D. (c II) elevation.

For the Arrochar saltmarsh, the location and elevation of one surface sample (sur) and two sediment cores (c I, c II) were measured, see figure 3.22. The samples with their elevation given in Chart Datum (C.D.) were

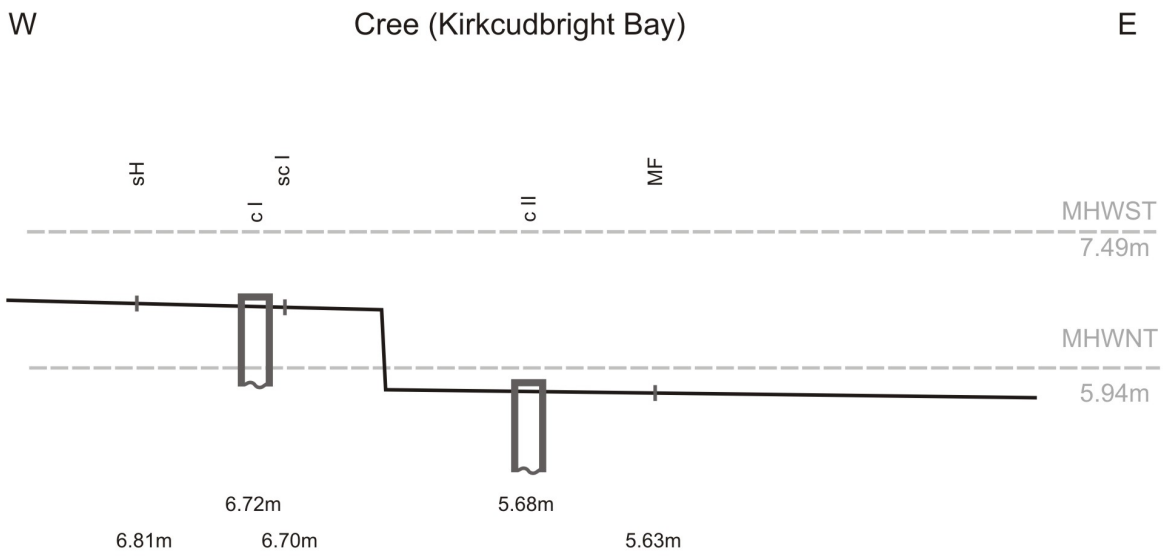

Figure 6.9.: Sketch of a marsh transect (Cree) showing the surface (black line) and measured elevation data (C.D.) which were calculated from the tides measured at Kirkcudbright Bay (MHWST = 7.50 m and MHWNT = 5.94 m, dotted grey lines) (Admiralty Tide Tables, 1977). The sediment cores (c I, c II) are indicated as cylinders. The arrangement of the samples and the core in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

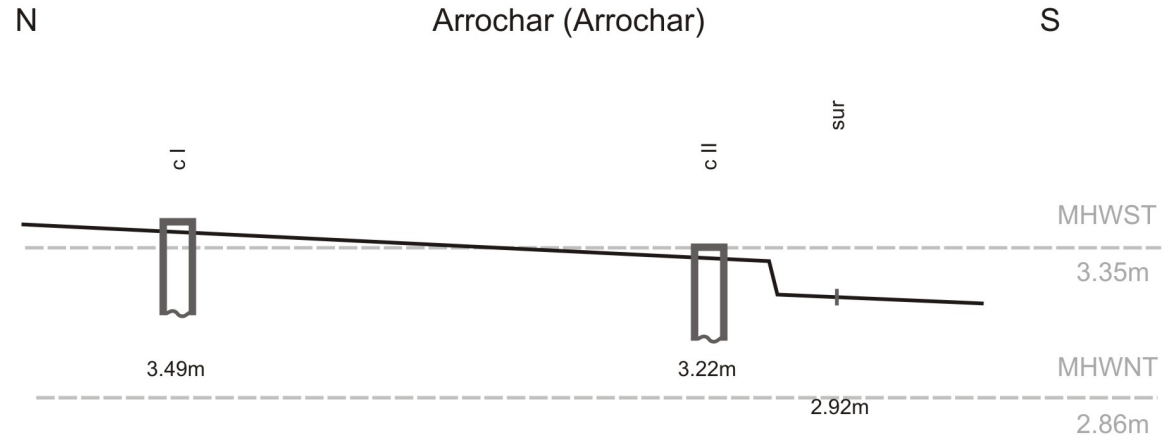

Figure 6.10.: Sketch of the Arrochar saltmarsh transect indicating its surface (black line) with elevation data in metres C.D. which were calculated from the tides measured at Arrochar (MHWST = 3.35 m and MHWNT = 2.87 m, dotted grey lines) (Admiralty Tide Tables, 1977). The sediment cores (c I, c II) are indicated as cylinders. The arrangement of the samples and the core in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

calculated from the tides measured at Arrochar (MHWST = 3.35 m and MHWNT = 2.87 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.10. The elevation of the surface sample was measured at 2.92 m C.D (sur), and no surface sample was below the MHWNT level. The two sediment cores were measured at 3.49 m C.D. (c I) and at 3.22 m C.D. (c II) elevation.

From the Loch Riddon saltmarsh, the location and elevation of four surface samples (sH, gr, ungr, MF) and three sediment cores (c I, c II, c III) were measured, see figure 3.24. The elevations of the samples were calculated as C.D. from the tides measured at Rothesay Bay (MHWST = 3.44 m and MHWNT = 2.87 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.11. The elevation of the highest surface sample was measured at 3.32 m C.D (up) and the lowest at 2.48 m C.D (MF), but none was measured below the MHWNT level. Two sediment cores were measured at 2.99 m C.D. (c I) and at 2.978 m C.D. (c II) above the MHWNT level, and one below at 2.50 m C.D. (c III).

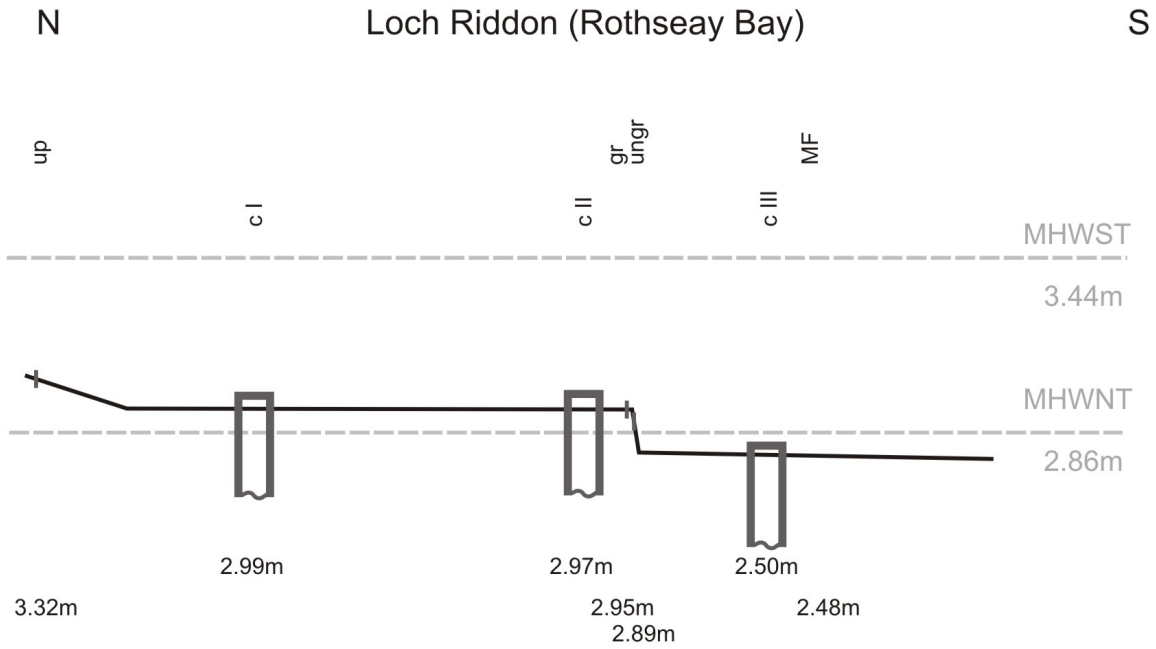

Figure 6.11.: Saltmarsh surface (black line) sketch with elevation data (C.D), showing a transect from the Loch Riddon study site. The data were calculated from the tides measured at Rothesay Bay (MHWST = 3.44 m and MHWNT = 2.87 m, dotted grey lines) (Admiralty Tide Tables, 1977). The sediment cores (c I, c II, c III) are indicated as cylinders. The arrangement of the samples and the core in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

For the Kyleakin saltmarsh, the location and elevation of four surface samples (sH, sL, SP, MF) and two sediment cores (c I, c II) were measured, see figure 3.26. The samples with their elevation given in Chart Datum (C.D.) were calculated from the tides measured at Kyle of Lochalsh (MHWST = 5.30 m and MHWNT = 3.90 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.12. The elevation of the highest surface

sample was measured at 4.95 m C.D (sH) and the lowest at 3.70 m C.D (MF), which was below the MHWNT level. No surface samples were measured above the MHWST level. Two sediment cores were measured at 5.00 m C.D. (c I) and at 4.90 m C.D. (c II) above the MHWNT level.

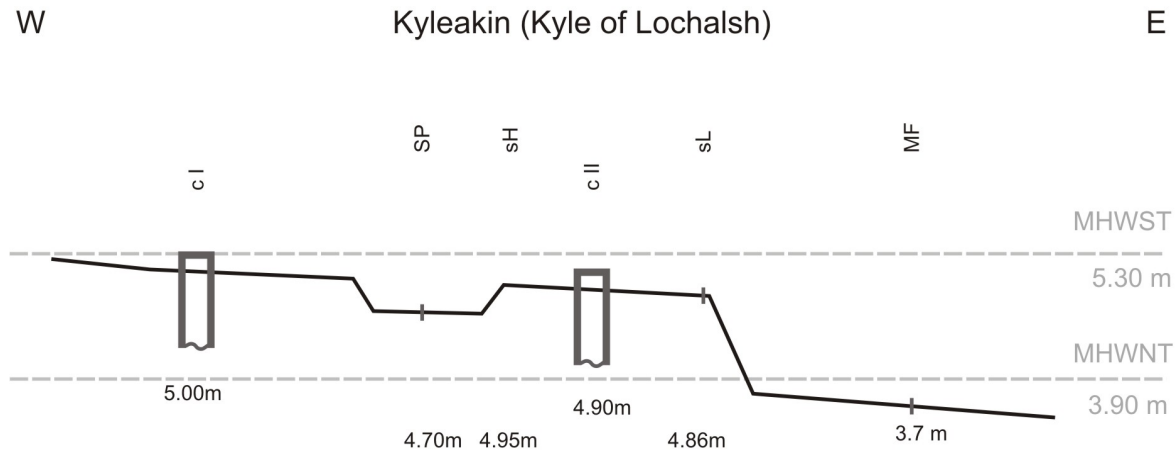

Figure 6.12.: Sketch of a Kyleakin saltmarsh transect indicating its surface (black line) with elevation data in metres C.D. which were calculated from the tides measured at Kyle of Lochalsh (MHWST = 5.30 m and MHWNT = 3.90 m, dotted grey lines) (Admiralty Tide Tables, 1977). The sediment cores (c I, c II) are indicated as cylinders. The arrangement of the samples and the core in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

From the Loch Ainort saltmarsh, the location and elevation of one surface sample (sur) and two sediment cores (c I, c II) were measured, see figure 3.28. The samples with their elevation in C.D. were calculated from the tides measured at Broadford Bay (MHWST = 5.30 m and MHWNT = 3.96 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.13. The elevation of the surface sample was measured at 5.15 m C.D (sur), which was below the MHWNT level. No surface samples were measured above the MHWST level. Two sediment cores were measured at 5.23 m C.D. (c I) and at 6.53 m C.D. (c II) above the MHWNT level.

For the Loch Sligachan saltmarsh, the location and elevation of one sediment core (C) was measured, see figure 3.30. The samples with their elevation given in C.D. were calculated from the tides measured at Broadford Bay (MHWST = 5.30 m and MHWNT = 3.96 m), which were found in the ATT (Admiralty Tide Tables, 1977), see figure 6.14. The elevation of the sediment core was measured at 3.66 m C.D. (c I), above the MHWNT level. No surface samples were measured.

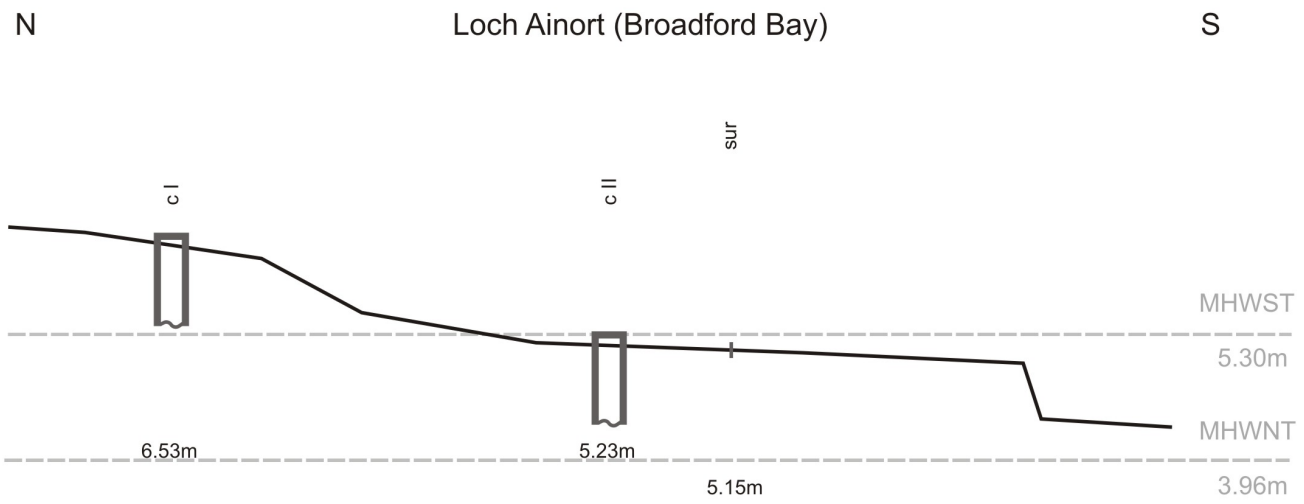

Figure 6.13.: Sketch of a Loch Ainort saltmarsh transect indicating its surface (black line) with elevation data in metres C.D. which were calculated from the tides measured at Broadford Bay (MHWST = 5.30 m and MHWNT = 3.96 m, dotted grey lines) (Admiralty Tide Tables, 1977). The sediment cores (c I, c II) are indicated as cylinders. The arrangement of the samples and the core in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

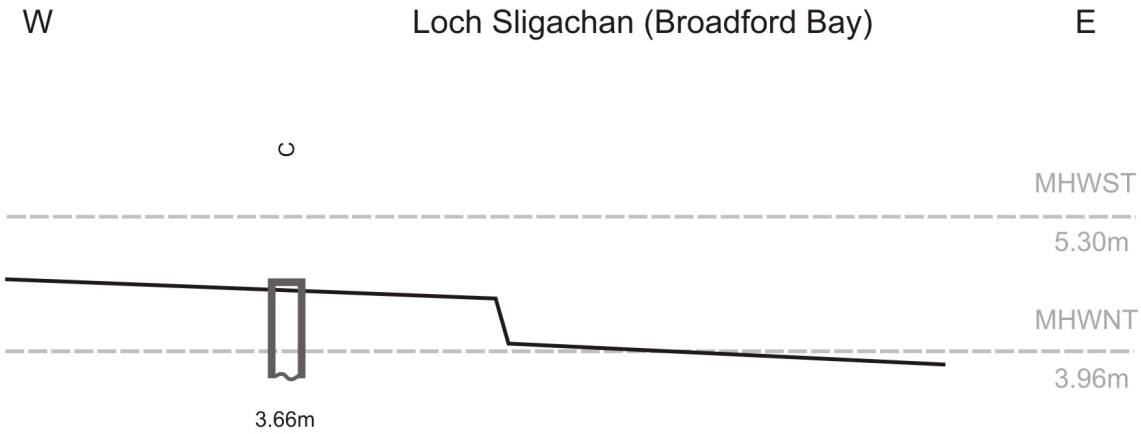

Figure 6.14.: Sketch of a Loch Sligachan saltmarsh transect indicating its surface (black line) with elevation data in metres C.D. which were calculated from the tides measured at Broadford Bay (MHWST = 5.30 m and MHWNT = 3.96 m, dotted grey lines) (Admiralty Tide Tables, 1977). One sediment core (C) is indicated as a cylinder. The arrangement of the samples and the core in the sketch does not correspond to their actual location on the marsh surface, but rather to their elevation in relation to the tide.

6.2. Meiofaunal seasonal data from Tollesbury saltmarsh

At the Tollesbury saltmarsh, a seasonal study was conducted from February 2012 to April 2013, see chapter 2.1.2 about methods. From the high (E = *Elytrigia*), mid (A = *Atriplex*) and low marsh (CR = creek rim) zones, surface samples were collected in a two month interval, see table 6.1 for a list of all samples. Then, the picked Foraminifera and Ostracoda were sorted and separated into living and dead assemblages. Nine Foraminifera species were identified from the high (E), mid (A) and low marsh (CR) samples (48 samples in total), and also nine Ostracoda species were found in the mid (A) and low marsh (CR) zones (32 samples in total). The high marsh (E) samples contained only Foraminifera, no Ostracoda. A list of the absolute abundance of Foraminifera can be found in the table D.3, and the absolute abundance of all with Rose Bengal stained tests in table D.4. As for the Ostracoda, table E.2 lists the absolute abundance of specimens per sample, and table E.3 shows absolute abundance of the living Ostracoda per sample. All mentioned Foraminifera and Ostracoda species are listed in chapter 5.

Table 6.1.: Sampling locations (and names) with their sampling date and all surface samples that were analysed in the seasonal study. Each month six samples were collected, two per saltmarsh zone (high marsh (E) = *Elytrigia*, mid marsh (A) = *Atriplex*, low marsh (CR) = creek rim).

Sampling location (name)	**sampling date**	**samples**
Tollesbury (T III)	16^{th} February 2012	E 4, E 5, A 3, A 7, CR 3, CR 7
Tollesbury (T IV)	26^{th} April 2012	E 12, E 13, A 8, A 12, CR 8, CR 12
Tollesbury (T V)	29^{th} June 2012	E 18, E 19, A 13, A 17, CR 13, CR 17
Tollesbury (T VI)	30^{th} August 2012	E 23, E 24, A 18, A 22, CR 18, CR 22
Tollesbury (T VII)	25^{th} October 2012	E 28, E 29, A 24, A 27, CR 23, CR 27
Tollesbury (T IX)	19^{th} December 2012	E 33, E 34, A 28, A 32, CR 28, CR 32
Tollesbury (T X)	27^{th} February 2013	E 38, E 39, A 33, A 37, CR 33, CR 37
Tollesbury (T XI)	30^{th} April 2013	E 43, E 44, A 38, A 42, CR 38, CR 42

As mentioned in chapter 2.1.2, to be able to compare the picked amount of identified living Foraminifera and Ostracoda per sample with each other, a unit volume or sample weight was necessary to be determined (Murray, 1973; Murray, 2006). For the Ostracoda, the whole sediment volume per sample, of 30 cm^3 for the mid (A) and 10 cm^3 for the low marsh (CR), was sorted through. This means that the Ostracoda specimens from the

A samples contained three times more shells than the CR samples. Their abundances per sample were therefore normalised for all mid and low marsh samples to Ostracoda per 30 cm^3, which is used here. However, the collected samples from each marsh zone contained too many Foraminifera to be picked through completely, except the low marsh (CR) samples. Therefore, the amount of sorted through sediment per sample was measured (in grams) and recorded, see table B.3 column: EX 125 µm [g]. Then the absolute abundances of Foraminifera per sample were normalised to Foraminifera per gram of sediment (F / g) which is used here (except the figures 6.15 and 6.16). Furthermore, the relative abundance of live / dead Foraminifera and Ostracoda species were calculated as well.

6.2.1. Foraminifera seasonal data

A total of 18 574 Foraminifera specimens from nine species and nine genera were picked and identified from the high (E), mid (A) and low marsh (CR) surface samples: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Cornuspira involvens* (Reuss, 1850), *Haynesina germanica* (Ehrenberg, 1840), *Quinqueloculina* spp., *Elphidium* spp., *Ammonia* spp. and *Globigerina* spp.. The latter one will be excluded from the seasonal study, because it is a planktonic Foraminifera that does not live in saltmarshes. Also, the test showed signs of transportation (abrasion) and was partly dissolved, and therefore could not have been alive when the sample was collected. A list of the absolute species abundance per sample, can be found in table D.3. The figures 6.15 and 6.16, are showing the absolute (black bars) as well as relative (grey bars, %) abundance of eight species per sample, the data are not normalised because the representation was not possible otherwise.

To distinguish the living and dead Foraminifera specimens of each species, Rose Bengal was used as stain. However, problems with this technique occurred, which are listed in chapter 2.1.2, but even so, it was tried to identify the stained tests as much as possible. Therefore, the agglutinated tests were also counted as alive (stained) when they showed a slight red colouring of the last four test chambers. And for the Miliolina (*Quinqueloculina*), they were counted as living when the whole test was coloured a dark pink. In all 48 surface samples, stained tests were identified.

All 48 saltmarsh surface samples, used in this seasonal study, contain a normalised absolute abundance of 27 519 (F / g) specimens per sample, ranging from 5 to 23 308 individuals per sample. The agglutinated form *J. macrescens* is the most common species, with a total absolute abundance of 155 625 (F / g) specimens in all samples. The lowest abundance shows *M. fusca* with a total of 76 (F / g) individuals, and it is the only species that was not stained red with Rose Bengal. Comparing the absolute abundance of all stained species from all samples, *H. germanica* had the lowest with 593 (F / g) individuals. However, the highest numbers of stained tests were counted from *J. macrescens*, with a total of 46 347 (F / g) individuals from all 48 samples. The figures 6.15 and 6.16 give an overview of all unnormalised absolute (black bars) and relative (grey bars, %) abundances of

Foraminifera specimens per species and sample. Furthermore, the figures also show the absolute abundance of stained tests (dotted line) compared to the absolute abundance of specimens per sample (black line). Additional, the live / dead relative abundance (%) of Foraminifera species per sample are shown in table 6.2.

From February 2012 (T III), all six surface samples (E 4, E 5, A 3, A 7, CR 3, CR 7) contain 22 172 (F / g) tests, showing a maximum of 6 985 individuals in sample A 7, and a minimum of 1 477 specimens in sample CR 3. The species *T. inflata* (36-72%) together with *J. macrescens* (64-28%) are predominating the high marsh samples (E 4 and E 5), but also continue to appear in all remaining samples as well, see figure 6.15. Both species also show their highest abundance of stained tests in the top to samples (each 21%), see table 6.2. The mid marsh samples (A 3 and A 7) are dominated by *J. macrescens* (70-59%), where *Quinqueloculina* spp. (11-20%) and *T. inflata* (each 16%) also appear with lower abundances. Hardly any high amounts of living forms were found from the mid marsh samples (max. 58 specimens in sample A 7). The low marsh sample CR 3 shows a Foraminiferal assemblage consisting of *J. macrescens* (33%), *Quinqueloculina* spp. (28%) and *Elphidium* spp. (28%). The latter one also shows a high abundance of stained tests (17%). The second low marsh sample (CR 7) is dominated by *Ammonia* spp. with 35%, lower abundances of *J. macrescens* (25%) and *Elphidium* spp. (29%) were also found. *Ammonia* spp. shows also a high abundance of stained tests (31%).

All six surface samples (E 12, E 13, A 8, A 12, CR 8, CR 12), from April 2012 (T IV), contain 32 557 (F / g) tests. The mid marsh sample A 8, with 11 970 individuals had the highest specimen numbers of all samples. The minimum amount of tests contains sample E 13 (1 775 specimens). The Foraminiferal assemblages in the high marsh (E 12, E 13) and mid marsh samples (A 8, A 12) are dominated by *J. macrescens* (max. 84%), see figure 6.15. A lower abundance of *T. inflata* (max. 29%) was also found in all four samples, as well as *Quinqueloculina* spp. (max. 16%) in the mid marsh samples. Low abundances of stained tests have been found in these samples as well, with sample A 8 containing the maximum amount of 80 specimens. The two low marsh samples (CR 8 and CR 12) show increased numbers of *Quinqueloculina* spp. (max. 45% in CR 8) and sample CR 12 is dominated by *Ammonia* spp. (48%), of which 39% were found alive, see table 6.2.

In the six surface samples (E 18, E 19, A 13, A 17, CR 13, CR 17) from June 2012 (T V), a total of 46 231 (F / g) tests was found. Sample A 13 contains the highest numbers of specimens (23 131) and E 18 the lowest (1 310). The Foraminiferal assemblages in all six marsh samples are dominated by *J. macrescens* (max. 83% in A 13), lower abundances of *T. inflata* (max. 25% in E 19) were also present in all six samples, see figure 6.15. 40% and 36% stained *J. macrescens* tests were picked from sample A 13 and A 17, see table 6.2. The highest abundance of *Quinqueloculina* spp. (24%) was found in sample A 17, which decreases in both low marsh samples (CR 13, CR 17) to a minimum of 5%. The species *Ammonia* spp. shows with 29% its highest abundance, as well as *Elphidium* spp. (27%) in sample CR 17. Here, 28% of the *Elphidium* spp. specimens were found stained.

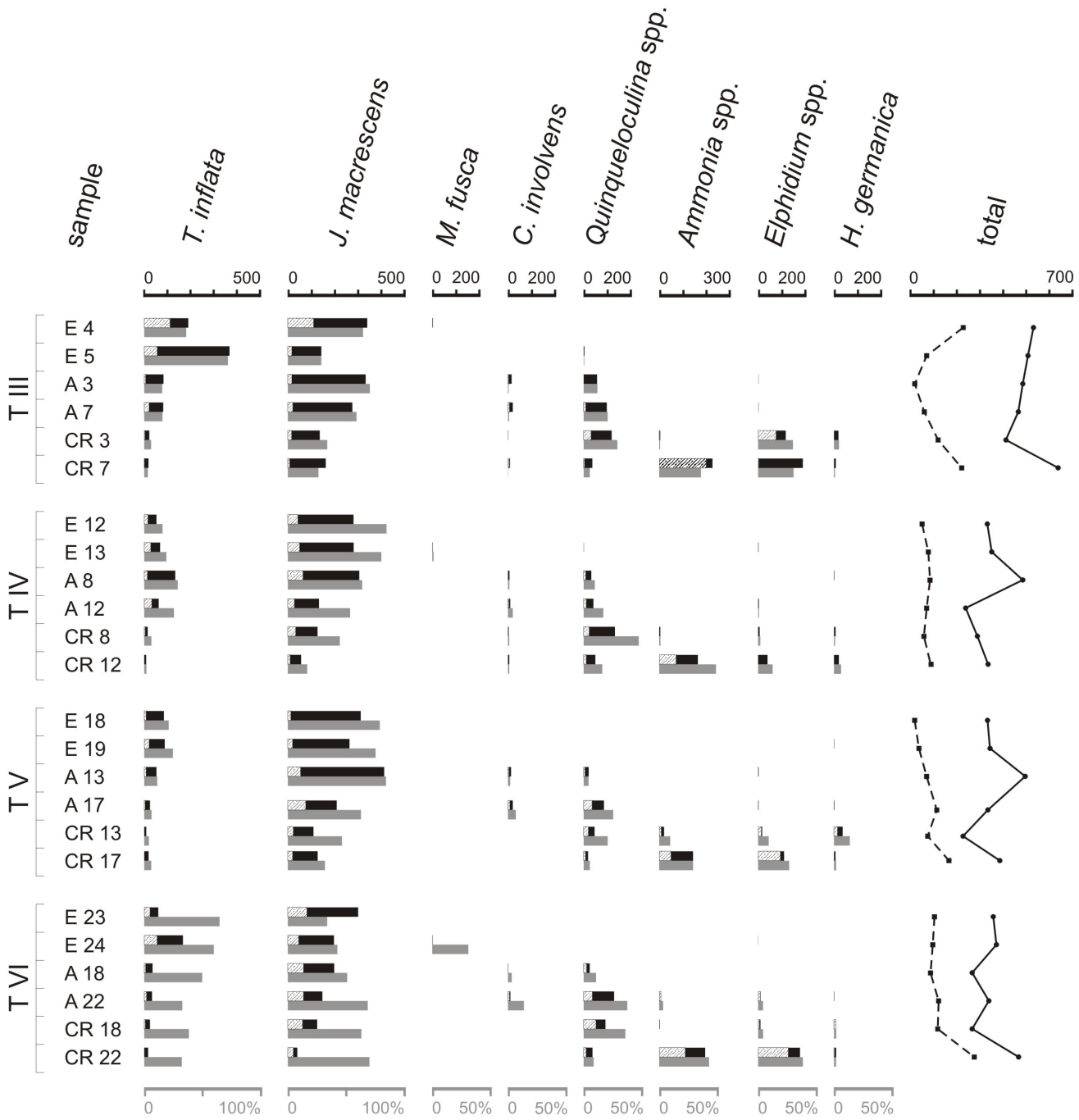

Figure 6.15.: Part I: Seasonal study from Tollesbury saltmarsh showing the Foraminifera analysis for the months February to August 2012. Per month, each two surface samples were collected from the high (E), mid (A) and low marsh zone (CB), shown are the most common species. Per sample, the unnormalised absolute abundance of specimens per species (black bars), including the Rose Bengal stained tests (white bars), are represented as well as their relative abundance (grey bars). Also, the absolute abundance of specimens (black line) as well as of Rose Bengal stained tests (dotted line) per sample is indicated.

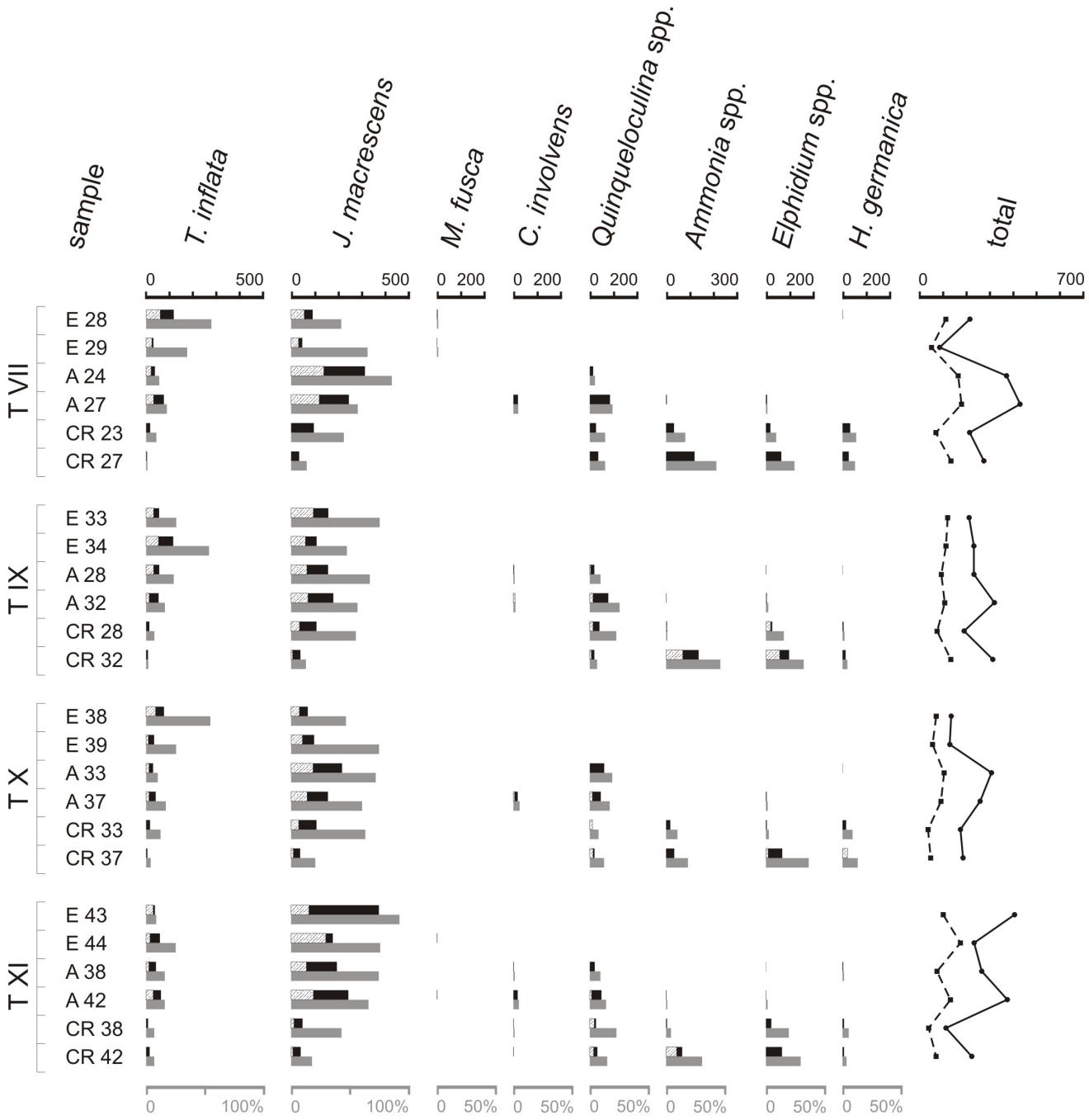

Figure 6.16.: Part II: Continuing with the months October to April 2013. Per month, each two surface samples were collected from the high (E), mid (A) and low marsh zone (CB), shown are the most common species. Per sample, the unnormalised absolute abundance of specimens per species (black bars), including stained tests (white bars), are represented, as well as the relative abundance (grey bars). Also, the absolute abundance of specimens (black line) as well as of Rose Bengal stained tests (dotted line) per sample is indicated.

From August 2012 (T VI), all six surface samples (E 23, E 24, A 18, A 22, CR 18, CR 22) contain 31 429 (F / g) specimens, showing a maximum of 17 143 individuals in sample A 18, and a minimum of 899 specimens in sample A 22. The highest abundance of the species *J. macrescens* (84%) can be found in the high marsh sample E 23, see figure 6.15. However, lower ones, with a minimum of 8% (CR 22), were found in the remaining five samples. From the species *J. macrescens*, 40% stained tests were picked from the mid marsh sample A 18, see table 6.2. Also a low abundance of *T. inflata* (max. 45% in E 24) is recognised from all six samples as well. *Quinqueloculina* spp. occur in the mid (A 18, A 22) and low marsh samples (CR 18, CR 22), with a maximum abundance of 37% in A 22. Its highest living numbers (20%), however, were found in sample CR 22. In this sample, the species *Elphidium* spp. appears in high abundances of 37%, of which 23% were found alive.

The six surface samples (E 28, E 29, A 24, A 27, CR 23, CR 27), from October 2012 (T VII), contain 43 449 (F / g) tests. Sample A 24 contains the highest numbers of specimens (27 519) and E 28 the lowest (111). The Foraminiferal assemblage in the high marsh sample E 28 is dominated by *T. inflata* with 60% relative abundance, see figure 6.16. The species *J. macrescens* also occurs in this sample with 56%. It is the dominating species in the other high marsh sample E 29 with 64%, as well as, with 85% and 57%, in both mid marsh samples (A 24, A 27). In sample A 24, 45% of its tests were stained, and 37% in sample A 27, see table 6.2. Sample A 27 also contains higher abundances of 19% of *Quinqueloculina* spp. and 18% of *T. inflata*. The low marsh samples (CR 23, CR 27) contain the same Foraminiferal assemblage, which consists of *T. inflata*, *J. macrescens*, *Quinqueloculina* spp., *Ammonia* spp. and *Elphidium* spp.. The highest abundances of *Ammonia* spp. (42%) and *Elphidium* spp. (23%) were found in sample CR 27.

In the six surface samples (E 33, E 34, A 28, A 32, CR 28, CR 32) from December 2012 (T IX), contain a normalised absolute abundance of 19 685 (F / g) tests. Sample A 32 contains the highest numbers of specimens (7 945) and E 33 the lowest (644). The species *J. macrescens* is most dominant in the high, mid and low marsh samples E 33, E 34, A 28, A 32 and CR 28, ranging from 54% to 74%, see figure 6.16. In sample E 33, its highest abundance (44%) of stained tests was found, see table 6.2. Higher abundances of *T. inflata* (16 to 26%,) are present in all high and mid marsh samples, than in the low marsh samples. The species *Quinqueloculina* spp. has its highest abundance in sample A 32 (24%), but was also found in both low marsh samples (CR 28, CR 32). The sample CR 32 contains 45% *Ammonia* spp., with 22% stained tests. *Elphidium* spp. also occurs in higher abundances (32%) than in the other low marsh sample. From this species, 18% stained tests were picked from sample CR 32.

From February 2013 (T X), all six surface samples (E 38, E 39, A 33, A 37, CR 33, CR 37) contain 20 651 (F / g) tests, showing a maximum of 9 770 individuals in sample A 37, and a minimum of 406 specimens in sample E 39. The species *T. inflata* dominates the high marsh sample (E 38) Foraminiferal assemblage with a relative abundance of 54%, see figure 6.16. Also, 28% stained *T. inflata* tests were found in this sample, see table 6.2. *J. macrescens*

shows high relative abundances (max. 74%) in the samples E 39, A 33, A 37 to CR 33. In sample A 33, 45% stained tests of *J. macrescens* were found. The low marsh samples (CR 33, CR 37) contain low amounts of *Ammonia* spp. (9-18%), and in sample CR 37 the highest abundance of *Elphidium* spp. (35%) was found, as well as 21% stained tests.

All six surface samples (E 43, E 44, A 38, A 42, CR 38, CR 42), from April 2013 (T XI), contain 38 424 (F / g) tests. The mid marsh sample A 42, with 16 895 individuals had the highest specimen numbers of all samples. The minimum amount of tests contains sample CR 38 (611 specimens). All samples show a Foraminiferal assemblages which is dominated by *J. macrescens* (max. 91% in E 43), see figure 6.16. From this species, in the high marsh sample E 44, 66% stained tests, and with each over 40% in both mid marsh samples (A 38, A 42), were found, see table 6.2. *T. inflata* only occurs in low abundances in all samples (7-25%). With a relative abundance between 8-22%, *Quinqueloculina* spp. occur in the mid and low marsh (CR 38, CR 42) samples. In sample CR 42, 30% of stained *Quinqueloculina* spp. specimens were found. The species *Elphidium* spp. shows its highest abundance (29%) in the sample CR 42.

Table 6.2.: All Tollesbury saltmarsh seasonal surface samples (48) showing relative abundance (more than 5%) of live (stained) / dead Foraminifera specimens for seven species per sample, including the absolute abundance of all specimens per sample (bulk), as Foraminifera per gram sediment. The samples were collected from three marsh zones, high (E = *Elytigia*), mid (A = *Atriplex*) to low marsh (CR = creek rim).

Sample	***T. inflata***	***J. macrescens***	***Quinqueloculina* spp.**	***Ammonia* spp.**	***Elphidium* spp.**	***H. germanica***	**bulk (F / g)**
E 4	21 / 15	21 / 43					3697
E 5	11 / 61	3 / 25					3774
A 3	1 / 15	3 / 67		0 / 11			3780
A 7	5 / 12	5 / 54		2 / 19			6985
CR 3	1 / 5	4 / 28		7 / 22		17 / 11	1477
CR 7		1 / 23		1 / 5	31 / 4	0 / 29	2459
E 12	5 / 11	11 / 0					2115

Continued on next page

Table 6.2 – continued from previous page

Sample	*T. inflata*	*J. macrescens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	bulk (F / g)
E 13	8 / 11	14 / 66					1775
A 8	3 / 26	13 / 51		2 / 5			11970
A 12	12 / 14	12 / 42		5 / 12			8467
CR 8	1 / 5	11 / 33		7 / 39			3986
CR 12	5 / 13		6 / 12	39 / 28	0 / 12	1 / 6	4244
E 18	2 / 18	3 / 76					1310
E 19	6 / 19	5 / 70					1432
A 13	7 / 9	40 / 73					23131
A 17	2 / 6	36 / 40		14 / 16			9098
CR 13	15 / 37		13 / 11	5 / 6	8 / 3	8 / 8	1362
CR 17	0 / 6	5 / 27	2 / 3	15 / 17	28 / 4		9898
E 23	7 / 9	22 / 62					2349
E 24	15 / 30	11 / 43					2095
A 18	4 / 12	40 / 51		8 / 5			17143
A 22	4 / 7	27 / 25		14 / 28			899
CR 18	2 / 8	25 / 31		21 / 17			1148
CR 22					20 / 16	23 / 8	7795
E 28	28 / 28	24 / 17					111
E 29	28 / 7	31 / 33					177
A 24	7 / 6	45 / 48					27519
A 27	10 / 10	37 / 29		5 / 16			10541
CR 23	0 / 9	18 / 33	8 / 7	13 / 8	7 / 3	4 / 9	1199
CR 27		1 / 11	7 / 6	22 / 22	18 / 5	2 / 9	3902

Continued on next page

Table 6.2 – continued from previous page

Sample	*T. inflata*	*J. macrescens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	bulk (F / g)
E 33	13 / 13	44 / 30					644
E 34	23 / 30	25 / 22					739
A 28	17 / 12	39 / 39		2 / 7			4989
A 32	7 / 12	35 / 34		8 / 19			7945
CR 28	1 / 7	22 / 37		12 / 13		14 / 3	1116
CR 32		3 / 10			25 / 23	19 / 14	4252
E 38	28 / 26	24 / 22					409
E 39	7 / 19	35 / 39					406
A 33	6 / 6	45 / 42		1 / 18			6184
A 37	8 / 12	39 / 34		5 / 14			9770
CR 33	0 / 12	38 / 46		11 / 2	0 / 9	1 / 8	1534
CR 37		12 / 14	11 / 6	0 / 18	6 / 32	21 / 2	2348
E 43	7 / 2	18 / 73					3575
E 44	8 / 17	66 / 8					845
A 38	10 / 11	45 / 50		0 / 8			14372
A 42	13 / 8	40 / 41		4 / 11			16895
CR 38	1 / 6	20 / 28		24 / 5		1 / 18	0 / 5 611
CR 42	1 / 6	6 / 14		12 / 5	30 / 10	0 / 29	2126

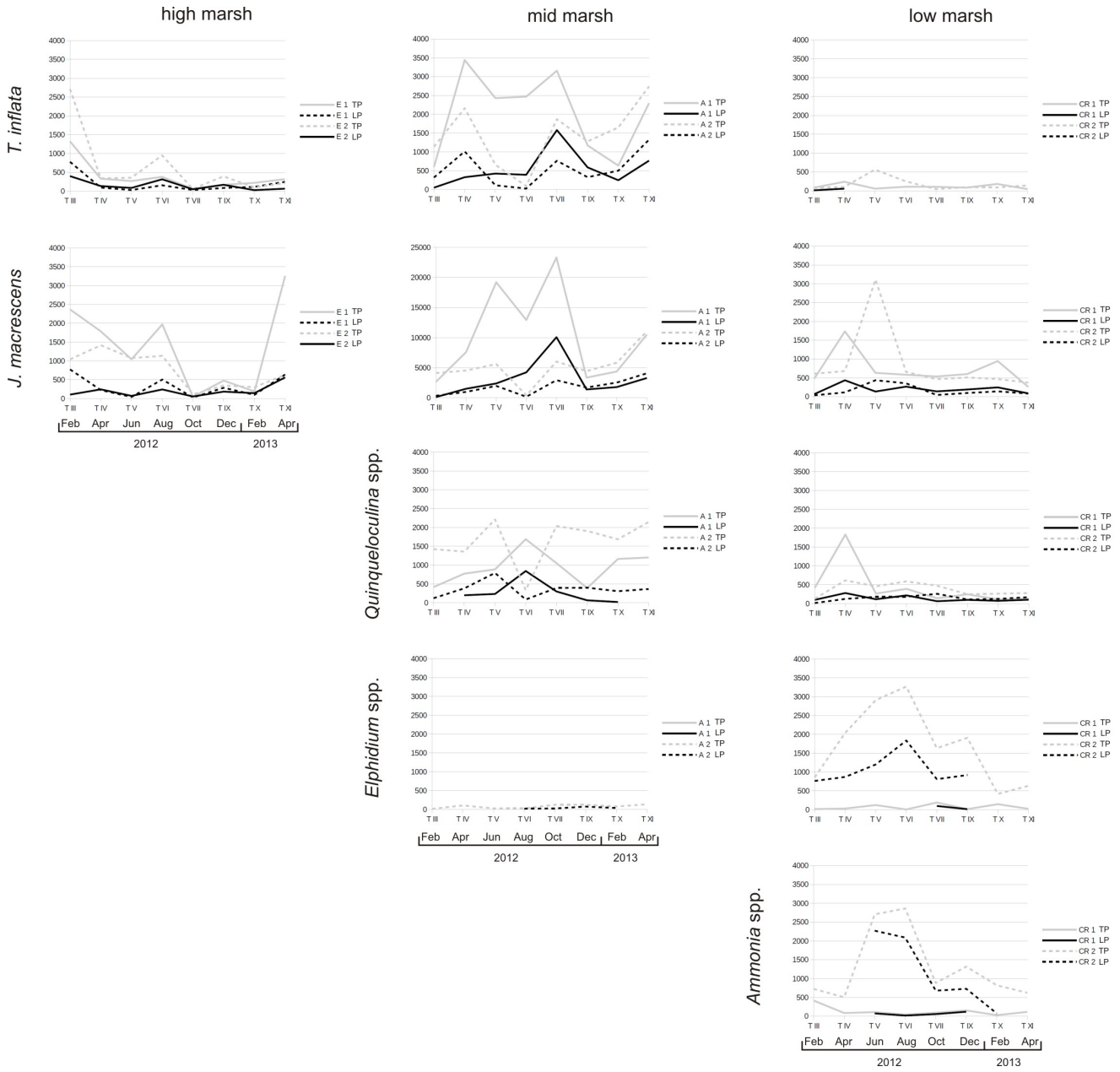

Figure 6.17.: Normalised absolute abundances (F/) of five common Foraminifera species per sample and marsh zone (E = high, A = mid, CR = low marsh) for the 14-month time period of the seasonal study, see description in text.

The graphs in figure 6.17 show the normalised absolute abundances of five Foraminifera species per sample and marsh zones (high, mid and low) over the 14-months time period of the seasonal study. Enough data were available at least for one marsh zone per *T. inflata*, *J. macrescens*, *Quinqueloculina* spp., *Elphidium* spp. and *Ammonia* spp., but not for *H. germanica*. Per plot the normalised living population (LP) and normalised total population (TP) for each sample is shown, e.g. *T. inflata* (top left) for high marsh showing four curves indicating the LP (live) and TP from both high marsh samples. Samples are summarised here, where E 4, E 12, E 18, E 23,

E 28, E 33, E 38 and E 43 are combined to E 1. Samples E 5, E 13, E 19, E 24, E 29, E 34, E 39 and E 44 are summarised to E 2. A 1 consists of A 3, A 8, A 13, A 18, A 24, A 28, A 33 and A 38. And A 2 consists of A 7, A 12, A 17, A 22, A 27, A 32, A 37 and A 42. The low marsh sample CR 1 combines the samples CR 3, CR 8, CR 13, CR 18, CR 23, CR 28, CR 33 and CR 38. The samples CR 7, CR 12, CR 17, CR 22, CR 27, CR 32, CR 37 and CR 42 are combined to CR 2.

T. inflata seems to only occur in high to mid marsh, with the highest total population in the mid marsh sample A 1, showing raised amounts from April to December 2012. The live population occurs later with two peaks, one in April 2012 in sample A 2, and the bigger one in October 2012 in sample A 1. The high marsh samples E 1 and E 2 show higher abundances in February 2012 as well as a small peak in August 2012. No trends can be seen for the low marsh samples. The graphs from *J. macrescens* indicate that this species occurs in all three marsh zones, with its highest abundance in the mid marsh zone with over 23 000 specimens in one sample for the TP in October 2012 in sample A 1. No clear trends for the LP for the high and low marsh can be seen, only TP trends with increased abundances before and after October peak in the mid marsh zone. *Quinqueloculina* spp. occur in the mid and low marsh zone, but predominantly in the former zone. In the latter one no trend in the LP is visible, only a small peak (with ca. 2 000 specimens) in April 2012 for the TP. The overall abundance is lower compared to the agglutinated forms. In the mid marsh zone opposing trends can be seen where sample A 1 shows a peak in Augusts (both LP and TP) and sample A 2 shows its minimum amount of specimens, with a slight peak of the LP in June 2012. Only from the low marsh sample CR 2 enough data from *Elphidium* spp. were available, however, living Foraminifera of this species were only found from February 2012 until December 2012. The TP peaks as well as the LP in August 2012. The same pattern can be seen for *Ammonia* spp., which also peaks at the same time (both LP and TP), but living forms were only found from August 2012 to February 2013.

The graphs in figure 6.18 shows the relative (%) abundances of the five Foraminifera species (mentioned above) per sample and marsh zone for the 14-months time period. Here, also for each marsh zone its two samples are summarised as described above, where E 1 and E 2 represent the high marsh, A 1 and A 2 the mid marsh and CR 1 and CR 2 the low marsh samples. Also, per sample, the living population percentages (LPP) and total population percentages (TPP) is shown per species and marsh zone.

The agglutinated species *T. inflata* shows a TPP (over 50%) and LPP (40%) peak around October 2012 for the sample E 2 and a smaller second LPP (over 20%) peaks in February 2013 for the sample E 1 in the high marsh zone. No clear trend is visible in the mid marsh zone, only slightly raised abundances in April and December 2012. Also *J. macrescens* shows its highest LPP (over 60%) values in the high marsh zone (sample E 2) which peaks around October 2012 (over 40%) and continues to raise until April 2013. A similar trend can be seen for the LPP in sample E 1, although there is no continued raising abundance until April 2013, only a slightly higher abundance compared to April 2012. The TPP shows its highest abundances (nearly 90%) before and after the LPP

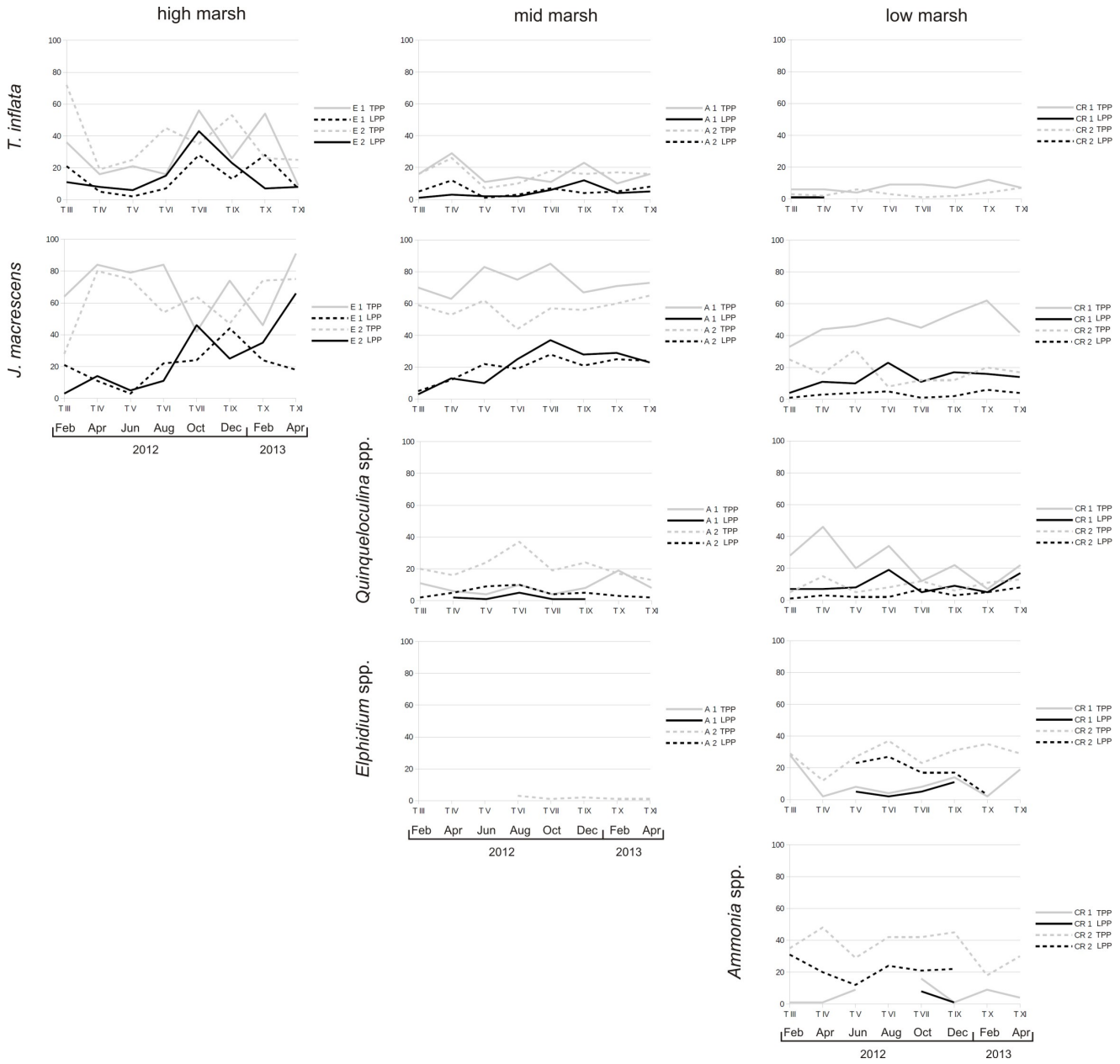

Figure 6.18.: Relative abundances (%) of five common Foraminifera species per sample and marsh zone (E = high, A = mid, CR = low marsh) for the 14-month time period of the seasonal study, see description in text.

peaks around October 2012. In the mid marsh zone, the TPP shows a high relative abundance for both samples as well as a slightly increasing LPP over autumn and winter until April 2013. The TPP in the low marsh zone is still high (max. 60%) for sample CR 1, but sample CR 2 shows lower abundances as well as no trend in the LPP. *Quinqueloculina* spp. show their highest TPP and LPP values in the low marsh zone, with peaks in April and August 2012, as well as one smaller one in December 2012. No clear trend for the LPP in the low marsh zone for *Elphidium* spp. can be seen, only raised values (ca. 40%) for the TPP in sample CR 2. *Ammonia* spp. shows also no clear trend in LPP and TPP, only raised values (over 40%) in sample CR 2 over the-months, with a minimum in February 2013.

Discussion of Foraminifera seasonal data

The Foraminifera seasonal data (figure 6.17) indicate that the agglutinated species *T. inflata* is most abundant in the high (E = *Elytrigia*) and mid (A = *Atriplex*) marsh zones. *J. macrescens* seems to be abundant in all three marsh zones, but with its highest absolute abundance in the mid marsh zone (over 23 000 F / g sediment). The only calcareous form *Quinqueloculina* spp. occurs in the mid marsh zone as well, in contrast to *Elphidium* spp. and *Ammonia* spp. which are restricted to the low marsh (CR = creek rim), and even there they were found only in one of two low marsh samples (CR 2). This distribution pattern is known from other saltmarshes as well, where agglutinated species dominate the high to mid marsh and calcareous forms are abundant in the low marsh area as well as mudflat (Scott & Medioli, 1978; Horton, 1997; Haslett et al., 2001; Gehrels & Newman, 2004; Horton & Edwards, 2006b; Mills, 2011; Kemp et al., 2012).

As for the life cycles, "[it] seems probable that most Foraminifera reproduce once a year in cool environments and more frequently in warmer environments. The birth rate is thus variable in time, it also varies with environmental conditions and with the size of the population" (Murray, 1973). A one year life cycle was identified for the species *T. inflata*, where relative abundance shows that it reproduces in the high marsh around October 2012 (figure 6.18). The same reproduction time for this species was also observed from the Cowpen Marsh (Cleveland, north-east England) (Horton, 1997; Horton & Edwards, 2006b), see figure 6.19. The species *J. macrescens* also seems to reproduce from August 2012 to April 2013 in the high marsh, and from June 2012 to April 2013 in the mid marsh area. A high abundance of living *J. macrescens* was also found during autumn in Cowpen Marsh for the high and mid marsh zones (Horton & Murray, 2006). Furthermore, two population peaks of this species were recorded from October 2001 (ca. 3 000 specimens) and August to February 2003 (max. over 5 000 specimens) in the South of the Bay of Bourgneuf, west France (Morvan et al., 2006), but both only from the mid marsh area. These data indicate, that *J. macrescens* probably reproduces in both marsh zones, however during offset time periods. The populations of the calcareous species is known to dominate the summer period (Scott & Medioli, 1980), which was also found in France (Morvan et al., 2006), as well as Cowpen Marsh, as indicated with the species

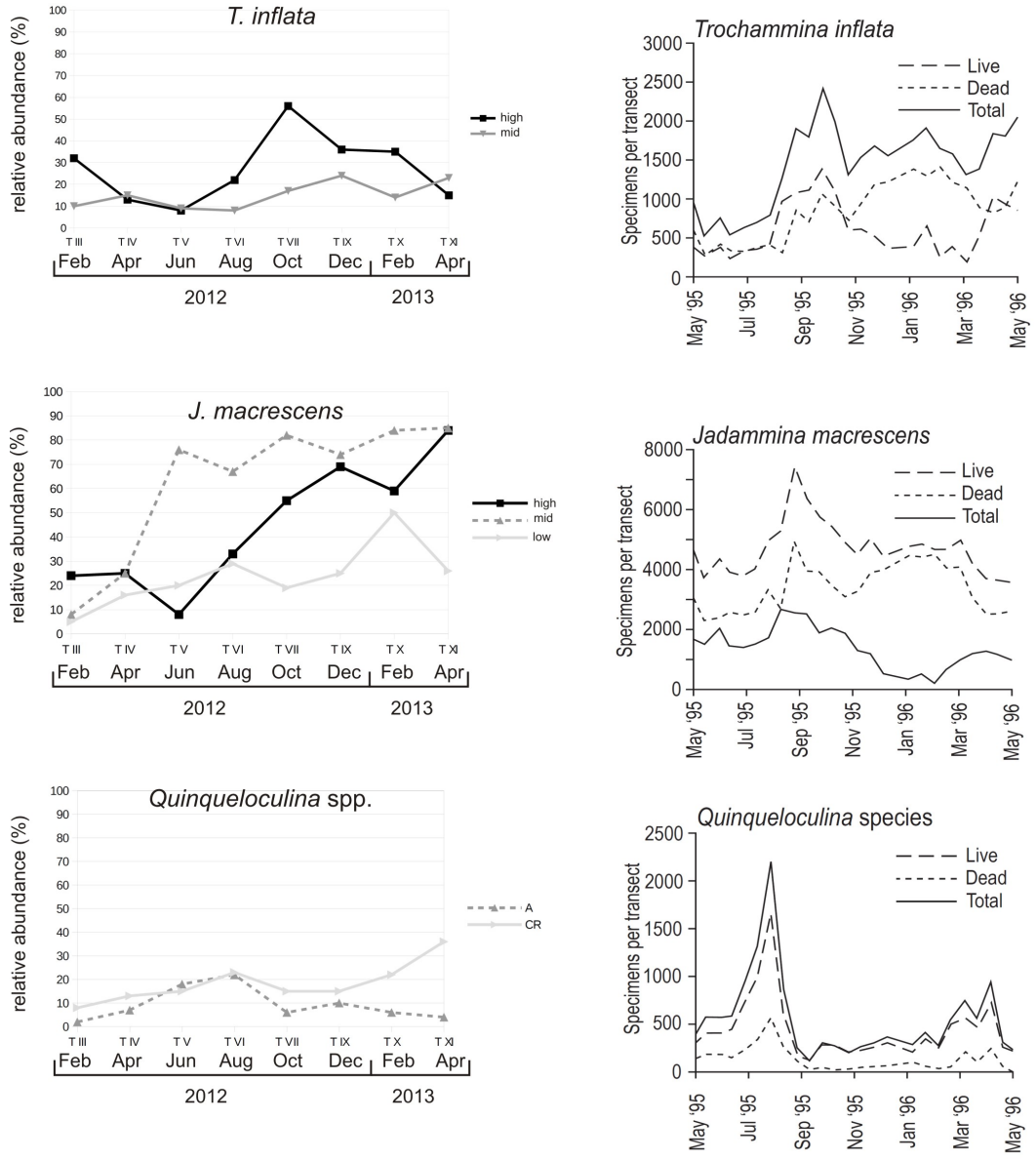

Figure 6.19.: Six diagrams, showing to the left the relative abundances of three Foraminifera species for a 14-months time period for three marsh zones (high = black, mid = dotted grey, low = grey line) from Tollesbury. The right graphs are showing the absolute abundances of the same species for the Cowpen Marsh (Cleveland, north-east England), images copied from Horton & Edwards (2006).

Quinqueloculina in figure 6.19. However, the relative abundance of the *Quinqueloculina* spp. from this study hardly shows a peak for the summer 2012, which could be correlated to dissolution in the saltmarsh sediment due to low pH conditions (Scott & Medioli, 1978). This will be analysed in a dissolution experiment in chapter 8. However, the total population (TP) peaks for all three calcareous species in this study indicate a high abundance as well as a living population in spring and summer 2012, see figure 6.17. There were too few data to analyse the life cycle for the species *H. germanica* and *C. involvens*. However, a similar distribution pattern for *M. fusca* was found at the saltmarsh in Nova Scotia, where the "[total] (live + dead) populations of *Miliammina fusca* generally constituted less than 20% of any given assemblage [...]. Empty tests far outnumbered stained individuals and persisted in both surface and subsurface sediments. This pattern differs from that of most other species and may reflect seasonal (winter) blooms of *M. fusca*" (Goldstein & Harben, 1993).

6.2.2. Ostracoda seasonal data

In total 696 Ostracoda specimens from nine species were found in the mid (A) and low marsh (CR) surface samples: *Cyprideis torosa* (Jones, 1850), *Hemicythere rubida* (Brady 1868), *Leptocythere castanea* (Sars, 1866), *Leptocythere ciliata* Hartmann, 1957, *Leptocythere porcellanea* (Brady, 1869), *Elofsonia baltica* (Hirschmann, 1909), *Loxoconcha malcomsoni* Horne & Robinson, 1985, *Cytherois fischeri* (Sars, 1866) and *Terrestricythere* sp., see table E.2 for a list of the absolute species abundance per sample. The figures 6.20 and 6.21 are showing the normalised absolute (black bars) and relative (grey bars, %) abundance of the most common Ostracoda species for all 32 samples, with normalised samples for Ostracoda per 30 cm^3 (O / 30 cm^3). Species with low abundances are summarised under others: *C. torosa*, *H. rubida*, *E. baltica*, *Terrestricythere* sp. and *C. fischeri*.

The stain Rose Bengal could not be used to distinguish the live / /dead ratio for Ostracoda, because all carapaces as well as valves were stained a bright pink. This is because, the stain colours all living organic content reddish, and the Ostracoda shells contained too high organic matter. Therefore, only the carapaces with soft parts still inside the shells were counted as alive.

All 32 saltmarsh surface samples, which were used in this seasonal study, contain a normalised absolute abundance of 1 020 specimens (O / 30 cm^3), ranging from 1 to 99 individuals per sample. The Ostracoda *L. ciliata* is the most abundant species, with an absolute abundance of 340 specimens for all samples. The lowest abundance shows *L. castanea* with a total of 110 individuals for all samples. From the 117 living Ostracoda specimen, also *L. ciliata* shows the highest abundance with 65 individuals and *L. castanea* the lowest with 12 specimens. The figures 6.20 and 6.21 give an overview of all absolute (black bars) and relative (grey bars, %) abundances of Ostracoda specimens per species and sample (O / 30 cm^3). Furthermore, the live / dead relative abundance (%) of Ostracoda species per sample are shown in table 6.3.

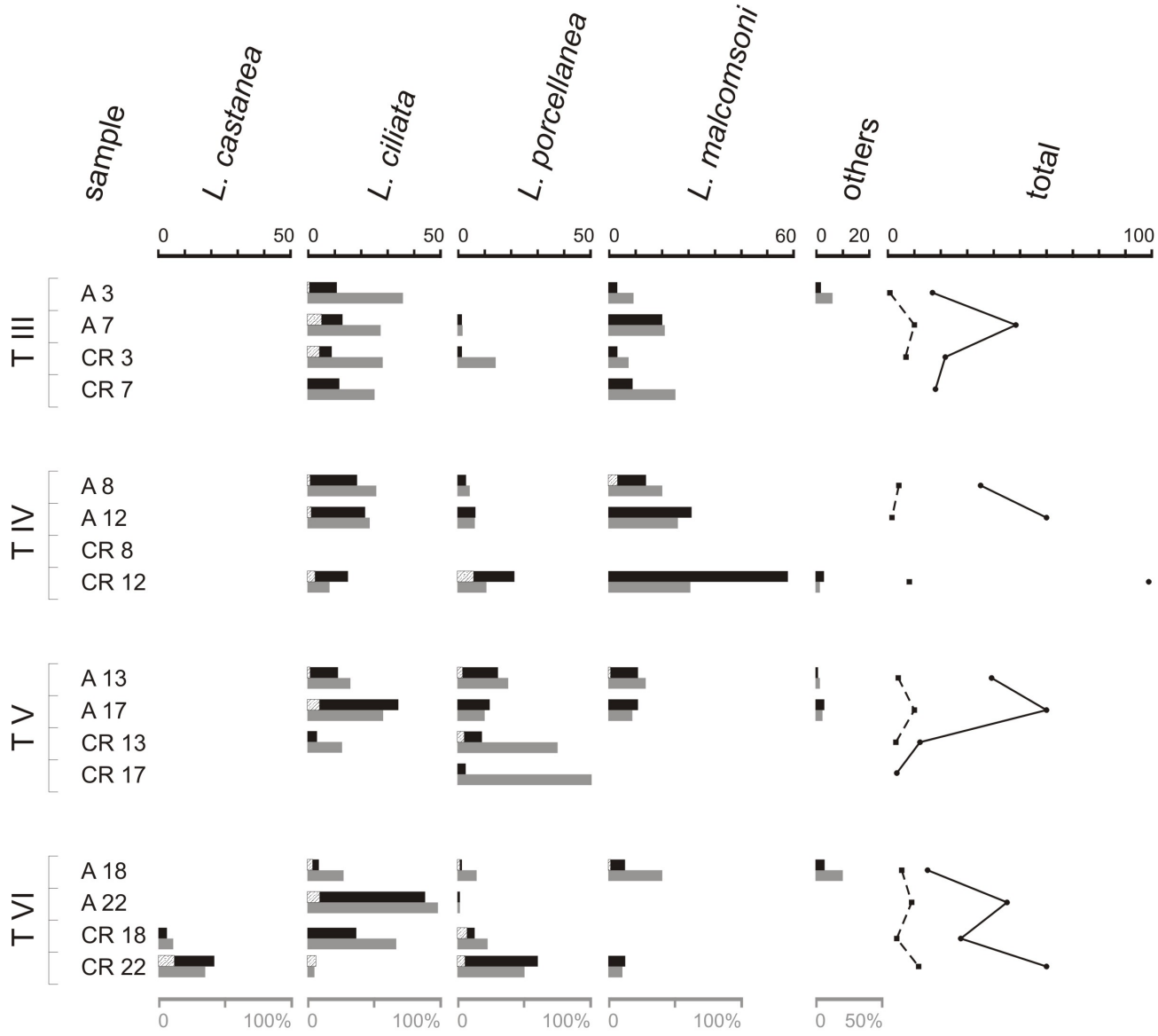

Figure 6.20.: Part I: Seasonal study from Tollesbury saltmarsh showing the Ostracoda (per 30 cm^3) analysis for the months February to August 2012. Per month, two surface samples each were collected from the mid (A) and low marsh (CB), shown are the most common species. Per sample, the absolute abundance of specimens per species (black bars), including the living (white bars), are represented as well as their percentage value (grey bars). Also, the absolute abundance of specimens (black line) as well as of living Ostracoda (dotted line) per sample is indicated.

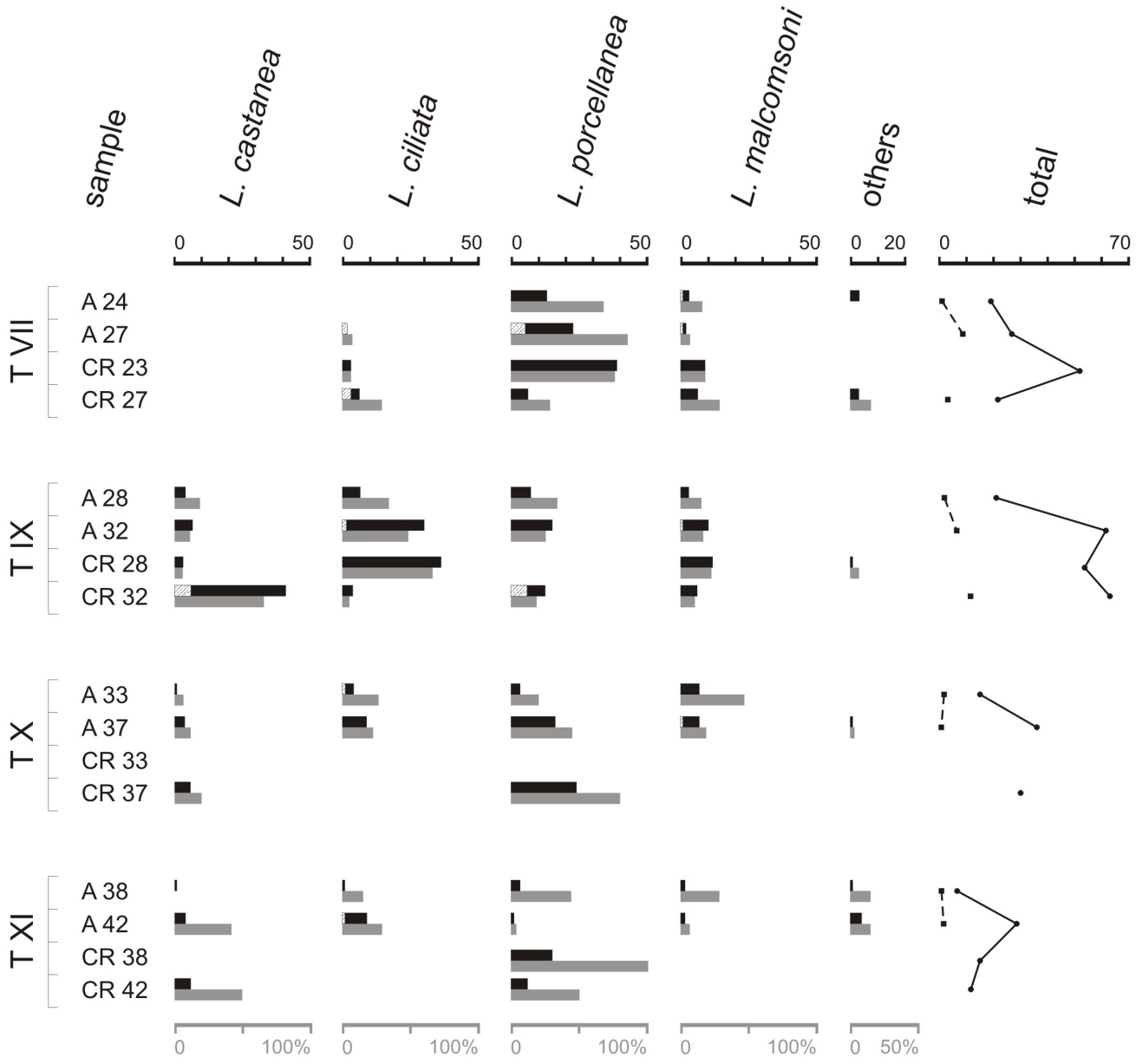

Figure 6.21.: Part II: Continuing with the months October to April 2013. Per month, two surface samples each were collected from the mid (A) and low marsh (CB), shown are the most common species. Per sample, the absolute abundance of specimens per species (black bars), including the living (white bars), are represented as well as their percentage value (grey bars). Also, the absolute abundance of specimens (black line) as well as of living Ostracoda (dotted line) per sample is indicated.

From February 2012 (T III), all four surface samples (A 3, A 7, CR 3, CR 7) contain 104 Ostracoda shells, showing a maximum of 48 individuals in sample A 7, and a minimum of 14 specimens in sample A 3. The mid marsh samples (A 3, A 7) contain high amounts of *L. ciliata* (54% and 71%), but also show lower abundances of *L. malcomsoni* (18% and 42%), see figure 6.20. Both species decrease in abundance in both low marsh samples (CR 3, CR 7). *L. porcellanea* appears in sample A 7 and CR 3 in low abundances. Only from the species *L. ciliata*, living specimens were found in sample A 7 (with 21%) and CR 3 (with 29%), see table 6.3.

All four surface samples (A 8, A 12, CR 8, CR 12), from April 2012 (T IV), contain 194 Ostracoda specimens. The mid marsh sample CR 12, with 99 individuals, had the highest specimen numbers of all samples. The minimum amount of tests contains sample A 8 (35 specimens). No specimens were found in sample CR 8. The mid marsh samples (A 8, A 12) contain an Ostracoda assemblage consisting of *L. ciliata* (51 and 37%), *L. porcellanea* (9-12%) and *L. malcomsoni* (40% and 52%), see figure 6.20. The latter one also shows in sample A 8 the highest abundance of living specimens (9%) for all samples from this month, see table 6.3. The low marsh sample CR 12 is dominated by *L. malcomsoni* (61%), the species *L. ciliata* and *L. porcellanea* show a lower abundance with 15% and 21%.

In the four surface samples (A 13, A 17, CR 13, CR 17) from June 2012 (T V), a total of 114 Ostracoda shells was found. Sample A 17 contains the highest numbers of specimens (60) and CR 17 the lowest (3 individual). In the mid marsh samples (A 13, A 17) the most common Ostracoda species are *L. ciliata* (31% and 57%), *L. porcellanea* (38% and 20%) and *L. malcomsoni* (28 and 18%), see figure 6.20. Hardly any living Ostracoda were found in these samples, but in sample CR 13, 25% of *L. porcellanea* were counted as alive, see table 6.3. Both low marsh samples (CR 13, CR 17) are dominated by *L. porcellanea* (75 and 100%). The only other species in sample CR 13 is *L. ciliata* (25%).

From August 2012 (T VI), all four surface samples (A 18, A 22, CR 18, CR 22) contain 147 Ostracoda specimens, showing a maximum of 60 individuals in sample CR 22, and a minimum of 15 specimens in sample A 18. Both mid marsh samples (A 18, A 22) contain a similar Ostracoda assemblage, which consists of *L. ciliata* (27% and 98%) and *L. porcellanea* (13% and 2%), and additional *L. malcomsoni* (40%) in sample A 18, see figure 6.20. The highest living relative abundance in both samples shows *L. ciliata* with 20%, see table 6.3. In both low marsh samples (CR 18, CR 22), additional to *L. ciliata* (67% and 5%) and *L. porcellanea* (22% and 15%), the species *L. castanea* occurs in low abundance (11% and 35%) as well.

The four surface samples (A 24, A 27, CR 23, CR 27), from October 2012 (T VII), contain 118 Ostracoda specimens. Sample CR 23 contains the highest numbers of specimens (51) and A 24 the lowest (19). Both mid (A 24, A 27) and low marsh samples (CR 23, CR 27) contain the same Ostracoda assemblage, which consists of *L. ciliata*, *L. malcomsoni* and *L. porcellanea*, see figure 6.21. The latter one is the dominating species in the samples A 24, A 27 and CR 23, with relative abundances of 68% to 76%. The sample CR 27 contains the same Ostracoda

species, but with lower abundances. From *L. ciliata*, living specimens were found in sample A 27 (19%) and CR 27 (14%), see table 6.3.

In the four surface samples (A 28, A 32, CR 28, CR 32) from December 2012 (T IX), contain a absolute abundance of 200 Ostracoda specimens. Sample CR 32 contains the highest numbers of specimens (63), and A 28 the lowest (21). All samples from this month contain *L. castanea* (max. 67% in CR 32), *L. ciliata* (max. 67% in CR 28) and *L. malcomsoni* (max. 22% in CR 28), see figure 6.21. In both mid marsh samples (A 28, A 32) and in sample CR 32 *L. porcellanea* (max. 33% in A 28) occurs as well. Low relative abundances of living *L. castanea*, *L. ciliata* and *L. porcellanea* were found with each 10%, see table 6.3.

From February 2013 (T X), all four surface samples (A 33, A 37, CR 33, CR 37) contain 81 Ostracoda shells, showing a maximum of 36 individuals in sample A 37, and a minimum of 15 specimens in sample A 33. No specimens were found in sample CR 33. Both mid marsh samples (A 33, A 37) contain *L. castanea* (7% and 11%), *L. ciliata* (27% and 22%) *L. porcellanea* (20% and 44%) and *L. malcomsoni* (47% and 19%), see figure 6.21. The highest relative abundance of living specimens were found in sample A 33 from the species *L. ciliata* (13%), see table 6.3. The low marsh sample (CR 37) contains only *L. castanea* and *L. porcellanea* in low abundances.

All four surface samples (A 38, A 42, CR 38, CR 42), from April 2013 (T XI), contain 62 Ostracoda specimens. The mid marsh sample A 42, with 28 individuals, had the highest specimen numbers of all samples. The minimum amount of tests contains sample A 38 (7 specimens). From this month, all samples contain only low abundances of Ostracoda, see figure 6.21, and no living specimens were found, see table 6.3. The mid marsh samples (A 38, A 42) show the same Ostracoda assemblage as the mid marsh samples from the previous month. The dominating species are *L. porcellanea* with 43% in A 38, and with each 29% *L. ciliata* and *L. malcomsoni* in sample A 42. The low marsh sample CR 38 contains only *L. porcellanea*, and the sample CR 42 also contains *L. castanea* as well.

Table 6.3.: All Tollesbury saltmarsh seasonal surface samples (32) showing relative abundance (more than 5%) of live / dead Ostracoda specimens for most common species per sample, including the absolute abundance of all specimens per sample (bulk), as Ostracoda per 30 cm^3. The samples were collected from two marsh zones, mid (A = *Atriplex*) to low marsh (CR = creek rim).

Sample	***L. castanea***	***L. ciliata***	***L. porcellanea***	***L. malcomsoni***	**others**	**bulk (O / 30 cm^3)**
A 3		6 / 65		0 / 18	0 / 12	17

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Table 6.3 – continued from previous page

Sample	*L. castanea*	*L. ciliata*	*L. porcellanea*	*L. malcomsoni*	others	bulk (O / 30 cm^3)
A 7		21 / 33		0 / 42		48
CR 3		29 / 29	0 / 29	0 / 14		21
CR 7		0 / 50		0 / 50		18
A 8		3 / 49	0 / 9	9 / 31		35
A 12		3 / 33	0 / 12	0 / 52		60
CR 8						0
CR 12		3 / 12	6 / 15	0 / 61		90
A 13		3 / 28	5 / 33	3 / 26		39
A 17		15 / 42	0 / 20	0 / 18		60
CR 13		0 / 25	25 / 50			12
CR 17			0 / 100			3
A 18		20 / 7	7 / 7	7 / 33	0 / 20	15
A 22		20 / 78				45
CR 18	0 / 11	0 / 67	11 / 11			27
CR 22	10 / 25	5 / 0	5 / 45	0 / 10		60
A 24			0 / 68	5 / 11	0 / 16	19
A 27		7 / 0	19 / 67			27
CR 23		0 / 6	0 / 76	0 / 18		51
CR 27		14 / 14	0 / 29	0 / 29	0 / 14	21
A 28	0 / 19	10 / 24	0 / 33	0 / 14		21
A 32	0 / 11	10 / 39	0 / 24	2 / 15		62
CR 28	0 / 6	0 / 67		0 / 22	0 / 6	54
CR 32	10 / 57	0 / 5	10 / 10	0 / 10		63

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Table 6.3 – continued from previous page

Sample	*L. castanea*	*L. ciliata*	*L. porcellanea*	*L. malcomsoni*	others	bulk (O / 30 cm^3)
A 33	0 / 7	13 / 13	0 / 20	0 / 47		15
A 37	0 / 11	0 / 22	0 / 44	3 / 17		36
CR 33						0
CR 37	0 / 20		0 / 80			30
A 38		0 / 14	0 / 43	0 / 29	0 / 14	7
A 42	0 / 46	7 / 21		0 / 7	0 / 14	28
CR 38			0 / 100			15
CR 42	0 / 50		0 / 50			12

The graphs in figure 6.22 show the normalised absolute abundances of three Ostracoda species per sample and marsh zones (mid and low) over the 14-months time period of the seasonal study. Enough data were available at least for one marsh zone per *L. ciliata*, *L. porcellanea* and *L. malcomsoni*, but not for *L. castanea*. Per plot the normalised living population (LP) and normalised total population (TP) for each sample is shown, e.g. *L. ciliata* (top left) for high marsh showing four curves indicating the LP (live) and TP from both mid marsh samples. Samples are summarised here, where A 3, A 8, A 13, A 18, A 24, A 28, A 33 are combined to A 1. And A 2 consists of A 7, A 12, A 17, A 22, A 27, A 32, A 37 and A 42. The low marsh sample CR 1 combines the samples CR 3, CR 8, CR 13, CR 18, CR 23, CR 28, CR 33 and CR 38. The samples CR 7, CR 12, CR 17, CR 22, CR 27, CR 32, CR 37 and CR 42 are combined to CR 2.

For the species *L. ciliata*, the low marsh sample A 2 contains most data to reconstruct the TP and a possible LP. The TP data show two peaks, one in August and one in December 2012, with a minimum value in-between. The LP values are higher in February and then over the summer months June to August 2012, not enough data are available for the winter until April 2013. For the low marsh, hardly any data are available, because not enough *L. ciliata* were present. Only a peak for the TP in August 2012 can be identified. For the species *L. porcellanea*, hardly any data for the LP are available, only the TP data have been plotted for the whole 14-month time period. Three peals are visible, two smaller ones in June 2012 and February 2013, with the largest peak in-between around

October 2012 (both A 1 and A 2 samples). Also high peaks can be seen for the low marsh, however the graphs are incomplete. For *L. malcomsoni* only the TP data from sample A 1 are complete to plot a graph for the-month time period. It shows higher abundances between February to August 2012, and a peak in February 2013. The data from the low marsh are incomplete to see any clear trends.

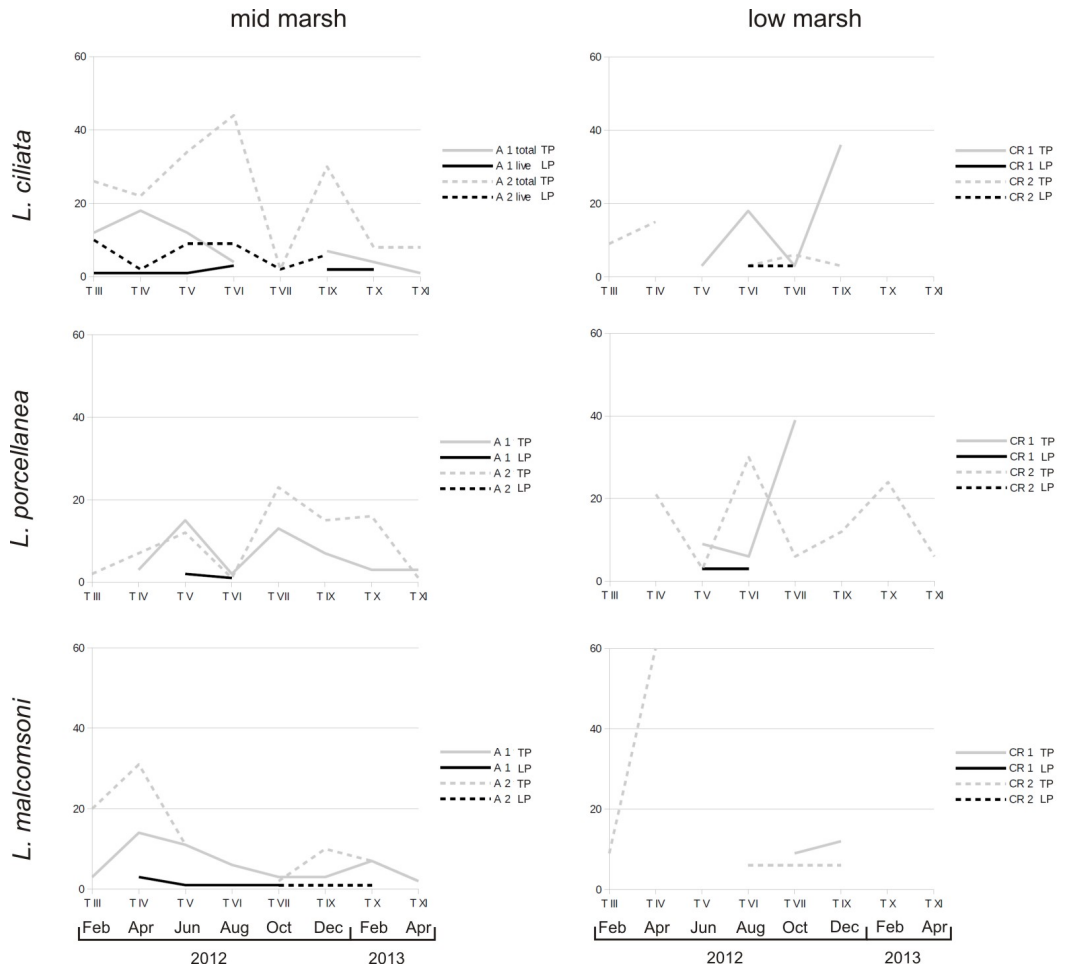


Figure 6.22.: Normalised absolute abundances of three common Ostracoda species per sample and marsh zone (A = mid, CR = low marsh) for the 14-month time period of the seasonal study, see description in text.

The graphs in figure 6.23 shows the relative (%) abundances of the three Ostracoda species (mentioned above) per sample and marsh zone for the 14-months time period. Here, also for each marsh zone its two samples are summarised as described above, where A 1 and A 2 represent the mid marsh and CR 1 and CR 2 the low marsh samples. Also, per sample, the living population percentages (LPP) and total population percentages (TPP) is shown per species and marsh zone.

The LPP and TPP graphs for *L. ciliata* in the mid marsh zone show a similar pattern than the LP and TP for the absolute abundances. Here, two TPP peaks appear on June (nearly 100%) and December 2012 (over 40%), with a minimum (10%) in-between, as well as higher LPP values (20%) over the summer months and in February 2012.

The low marsh data are incomplete and show only TPP peaks for the CR 1 sample. The species *L. porcellanea*

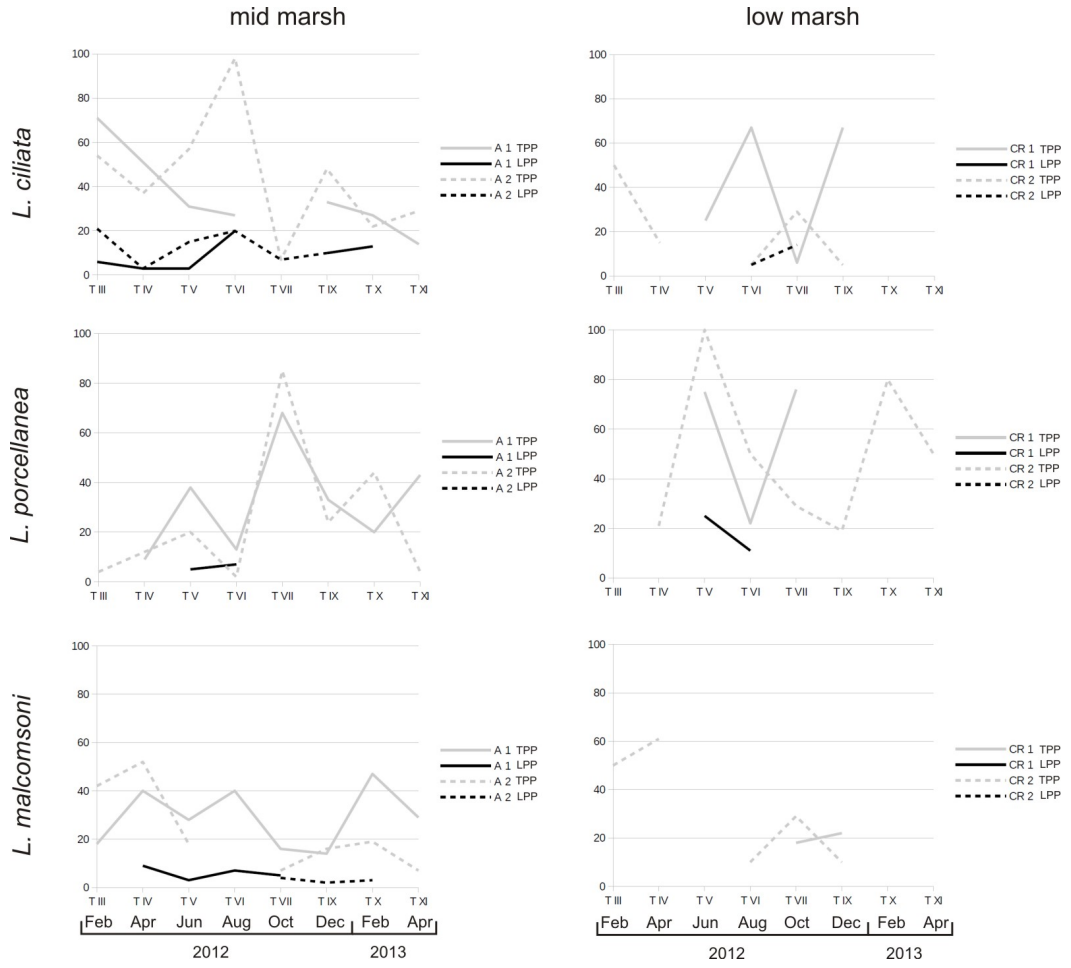


Figure 6.23.: Relative abundances (%) of three common Ostracoda species per sample and marsh zone (A = mid, CR = low marsh) for the 14-month time period of the seasonal study, see description in text.

seems to have three TPP peaks, one in June (40%), in October (60-80%) 2012 and February 2013 (over 40%). The inconclusive graphs for the TPP in the low marsh samples show different peaks, except for February 2013. For the species *L. malcomsoni* only enough data are available for the mid marsh zone, and only the TPP. Here, it shows higher abundances from April to August 2012 (each 40%) as well as February 2013 (over 40%). No clear trend can be seen for the LPP.

Besides the identified dead and living Ostracoda, also the carapaces and valves (table E.4) of the three most common species were counted (figure 6.24). The absolute abundance of *L. malcomsoni* carapaces peaks in February and April 2012, with a peak of its valves in February 2013. In contrast, *L. porcellanea* shows a peak of its valve abundance in June, October 2012 and February 2013. Only a high abundance of *L. porcellanea* carapaces was found in October 2012 and April 2013. *L. ciliata* is the smallest of all three species and was found throughout the year with a peak in carapace abundance in July and August 2012.

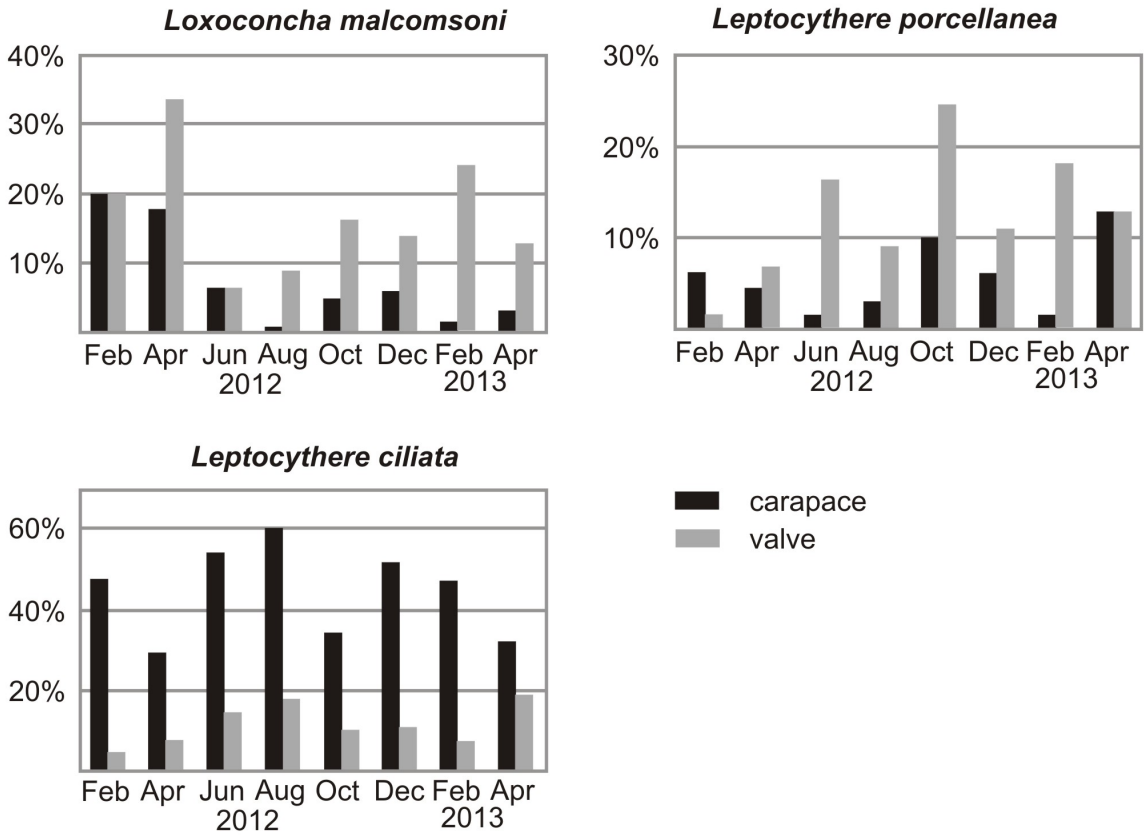


Figure 6.24.: Ostracoda seasonal study with its 14-months time period starting in February 2012 until April 2013. The three plots show the absolute abundances of the counted carapaces (black) and valves (grey), every two months, for the three most common Ostracoda species found at Tollesbury saltmarsh.

Discussion of Ostracoda seasonal data

The only complete data to reconstruct a living population from the four most common Ostracoda was for the species *L. ciliata* (figure 6.23). This mid marsh (A = *Atriplex*) Ostracoda shows a relative abundance of living specimens with a peak (40%) in August 2012 (figure 6.25), which could indicate one life cycle per year. This data would fit the assumption that saltmarsh Ostracoda can have a one to three year life cycle (Horne & Boomer, 2000). The counted carapaces peak in August 2012 as well, however a high abundance of it was also found throughout the year, indicating a low energy Thanatocoenosis (Boomer et al., 2003). This could have led to the slightly increased relative abundance that occurs in February 2012 (30%) and December 2012 (20%) (figure 6.24).

From the other two identified species *L. porcellanea* and *L. malcomsoni*, at least the abundances of the total populations (figure 6.22), would indicate that both species are living on the mid marsh. The found *L. malcomsoni* carapaces would indicate that it has one generation every two years or a short generation time (figure 6.24). This species was also found alive in March 1996 at Stiffkey, Norfolk, as well as in October 1995 on the Isle of Wight (Horne & Boomer, 2000) (see Ostracoda study in chapter 6.4). In contrast, *L. porcellanea* shows two carapace

peaks, one in October and one in April 2014, which might also indicate a short generation time. The counted carapaces and valves for both species, nearly fits the pattern of their total population percentages (TPP), as shown in figure 6.23.

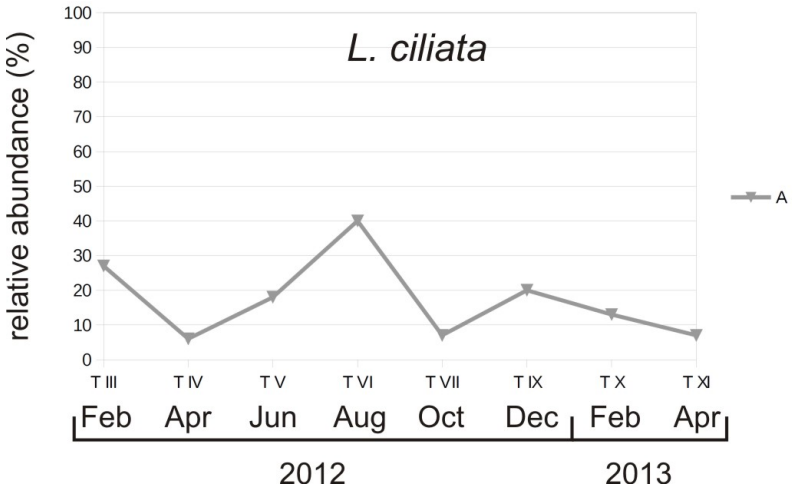


Figure 6.25.: Diagram showing relative (%) abundance of the Ostracoda species *L. ciliata* against a 14-month time period for the mid marsh zone (A).

L. castanea, as seen in the figures 6.20 and 6.21, was found only from August 2012 to April 2013 in mostly low abundances (11-56 individuals) in the low marsh zone, with no specimens in October 2012. It could be possible that it migrates to the low marsh zone during this time, no specimens were found on the mid marsh. Horne & Boomer (2000) suggested that this species is able to produce "desiccation-resting eggs during autumn" which would not be the case here, since it is most abundant in December 2013 (with 56 specimens). Horne (1980) found this species reproducing at least one generation per year with overwintering adults in Portishead, in the Severn Estuary. For conclusive data, for all Ostracoda species, a suggested re-sampling campaign with a bigger sample volume than 30 cm^3 should be conducted in the future to investigate the living populations of Ostracoda at Tollesbury saltmarsh. Furthermore, the problem of a restricted spatial distribution and the resulting patchiness cannot be excluded for all Ostracoda species, as it is the case on the Isle of Wight (chapter 6.4).

6.3. Analyses of saltmarsh surface samples and sediment cores

The results of the Foraminifera and Ostracoda analyses from all surface samples and sediment cores from all eight saltmarsh study sites, including particle size analysis (PSA), are discussed in this section: Tollesbury, Two Tree Island, Gann, Loch Riddon, Kyleakin, Loch Ainort, Loch Sligachan and Holkham with Stiffkey. The data about absolute abundance of Foraminifera and Ostracoda species per sample can be found in the appendix D and E. In total, 40 027 Foraminifera individuals from 17 species and 7 500 Ostracoda specimens from 35 species were

found in 188 samples. The tables 6.4 and 6.5 give an overview about Foraminifera and Ostracoda species per study site. All mentioned Foraminifera and Ostracoda species are listed in chapter 5.

Table 6.4.: Foraminifera species distribution of all analysed study sites: Tollesbury (T), Two Tree Island (TTI), Loch Riddon (LR), Kyleakin (KY), Loch Ainort (LA), Loch Sligachan (LS) and Holkham (Hol) with Stiffkey (SK). The observed Foraminifera species from the Isle of Wight (IW) are included here as well.

species	**T**	**TTI**	**IW**	**G**	**LR**	**KY**	**LA**	**LS**	**Hol**	**SK**
Ammobaculites sp.			X							
Eggerella scaber			X							
Jadammina macrescens	X	X	X	X	X	X	X	X	X	X
Trochammina inflata	X	X	X	X	X	X	X	X	X	X
Haplophragmoides wilberti			X		X	X	X	X		
Miliammina fusca	X	X	X	X	X	X	X	X		
Reophax moniliformis	X		X							
Cornuspira involvens	X			X						
Quinqueloculina spp.	X	X	X	X						X
Allogromia sp.			X	X	X					
Asterigerinata spp.		X								
Ammonia spp.	X	X	X	X					X	
Cibicides spp.		X								
Elphidium spp.	X	X	X	X	X				X	X
Haynesina germanica	X	X	X	X					X	
Globigerina spp.	X	X								
Lagena spp.		X	X							

Table 6.5.: Ostracoda species distribution of all analysed study sites: Tollesbury (T), Two Tree Island (TTI), Isle of Wight (IW), Loch Riddon (LR), Kyleakin (KY), Loch Ainort (LA), Loch Sligachan (LS) and Holkham (hol) with Stiffkey (SK).

species	**T**	**TTI**	**IW**	**G**	**LR**	**KY**	**LA**	**LS**	**Hol**	**SK**
Pontocythere elongata		X								
Cytherura gibba	X	X		X						
Cytheropteron cf. *depressum*		X								
Cytheropteron cf. *monoceros*		X								
Cytheropteron punctatum		X								
Hemicytherura cf. *cellulosa*		X								
Microcytherura sp.		X								
Semicytherura sp.		X								
Cyprideis torosa	X	X	X			X				
Aurila woutersi		X								
Hemicythere rubida	X		X							
Hemicythere villosa		X								
Heterocythereis albomaculata		X								
Leptocythere baltica	X			X						
Leptocythere castanea	X	X	X	X	X					
Leptocythere ciliata	X	X	X	X						
Leptocythere fabaeformis			X							
Leptocythere porcellanea	X	X	X	X						
Leptocythere psammophila		X								
Elofsonia baltica	X			X						
Hirschmannia viridis		X	X							
Loxoconcha elliptica	X	X		X						
Loxoconcha malcomsoni	X									
Loxoconcha rhomboidea		X	X							
Palmoconcha laevata		X								
Cytherois fischeri	X	X	X	X						
Cytherois cf. *stephanidesi*			X							

Continued on next page

Table 6.5 – continued from previous page

species	T	TTI	IW	G	LR	KY	LA	LS	Hol	SK
Cytherois sp.		X								
Paradoxostoma ensiforme		X								
Paradoxostoma trieri		X	X							
Carinocythereis cf. *whitei*		X								
Hiltermannicythere cf. *emaciata*		X								
Xestoleberis labiata			X							
Xestoleberis sp.		X								
Terrestricythere cf. *elisabethae*	X		X							

As stated in chapter 6.2, to compare the picked microfossils abundances per sample with each other, the samples had to be normalised, by converting the absolute abundance of all specimens per sample into specimens per gram sediment (e.g. for Foraminifera: F / g). This was necessary for the seasonal study samples, because the living abundances per samples had to be compared (Murray, 1973; Murray, 2006). However, for the samples used in this chapter, the calculated normalised relative abundances of the surface and core samples showed no significant differences between the normalised and unnormalised specimens per sample. Therefore, the unnormalised specimens per sample can also be used for comparison.

6.3.1. Tollesbury saltmarsh samples

From the Tollesbury saltmarsh, 17 surface samples as well as 42 sediment core samples, from a 2.5 m (TCE) and a 5 m deep (TC) core, were extracted. The surface samples contain Foraminifera and Ostracoda, whereas, only Foraminifera were found in both sediment cores. Furthermore, PSA was conducted for both saltmarsh cores, as well as for a third one (c II). For an overview of the sampling locations, see chapter 3.2.1.

Tollesbury surface samples

The 17 saltmarsh surface samples contain 7 763 Foraminifera and 478 Ostracoda specimens. Samples were collected from the high (E 2, E 9, Terr, P 3), mid (A 2, AA 1), and low marsh (S 2, S 4, S 8, CR 1, CR 2, CB 1, CB 2) zones, as well as from four salt pans (SP 1, SP 3, SP 4, SP 8). In all 17 surface samples, 9 Foraminifera species belonging to 9 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Reophax moniliformis* Siddall, 1886, *Cornuspira involvens* (Reuss,

1850), *Quinqueloculina* spp., *Ammonia* spp., *Elphidium* spp. and *Haynesina germanica* (Ehrenberg, 1840), see table D.1 about absolute abundance of all species per sample.

The high marsh samples E 2 and E 9, collected from the *Elytrigia* plant zone, contain 176 and 941 tests. Both samples also show a similar Foraminiferal assemblage, containing high abundances of the agglutinated forms *T. inflata* (45 and 13%) and *J. macrescens* (54 and 85%), see figure 6.26. The sample Terr was collected from the roots of the marsh plant *Aster tripolium*, to collect the Ostracoda *Terrestricythere* sp., but 550 tests were found, mostly containing *T. inflata* (28%) and *J. macrescens* (67%). The high-mid marsh sample P 3 was extracted from the *Puccinellia* plant zone, and shows a similar Foraminiferal assemblage which is dominated by agglutinated forms, as the other high marsh samples. In total, 564 specimens mostly of *T. inflata* (25%) and *J. macrescens* (72%) were identified. The mid marsh samples A 2 and AA 1 were collected from the *Atriplex* plant zone (and algae =AA) and contain the same Foraminiferal assemblage, with AA 1 showing only a lower specimen abundance (50 individuals). A 2 contains a total of 688 tests of *J. macrescens* (44%), *Quinqueloculina* spp. (35%), *C. involvens* (15%) and *T. inflata* (6%). The smples S 2, S 4 and S 8 were collected at the low marsh plant *Salicornia*, all containing the same assemblage, ranging from most abundant to lowest: *Quinqueloculina* spp., *Ammonia* spp., *J. macrescens*, *Elphidium* spp. and *T. inflata*, *H. germanica*. The four salt pan samples (SP 1, SP 3, SP 4, SP 8) were collected, to test if the species *R. moniliformis* exclusively occurs in this environment. It was found in all salt pan samples only. SP 1 and SP 2 were exacted from high marsh, and the remaining Foraminifera species reflect the assemblages of this marsh zone, with high abundances of *J. macrescens* (55-57%) and *T. inflata* (30-31%). Samples SP 4 and SP 8 were collected from mid-low marsh zones, and also contain high abundances of the calcareous form *H. germanica* (20-59%). Furthermore, two samples were collected from the marsh edge (creek rim = CR 1, CR 2) and two from the bottom of the creeks (CB 1, CB 2). These samples were also counted as low marsh samples. The samples CR 1 and CR 2 contain the same Foraminiferal assemblage consisting mainly of *Quinqueloculina* spp. (50 and 94%), *Elphidium* spp. (26 and 2%) and *J. macrescens* (12 and 2%). The Foraminiferal assemblage from the samples CB 1 and CB 2 contain predominantly *J. macrescens* (20 and 63%), *Elphidium* spp. (37 and 2%), *H. germanica* (28 and 5%) and *T. inflata* (6 and 28%). However, in both samples, the tests show traces of transportation (abrasions), where the last test chambers are often broken.

The surface samples from the Tollesbury saltmarsh sites show a decreasing trend in agglutinated Foraminifera (*T. inflata* and *J. macrescens*), and an increasing trend in calcareous species (*Quinqueloculina* spp., *H. germanica*, *Ammonia* spp., *Elphidium* spp.) from high (*Elytrigia*) to low (*Salicornia*) marsh including the creek sediment, see figure 6.26. The species *R. moniliformis* appears only in salt pans and can therefore be used to identify this marsh zone, see figure 6.26.

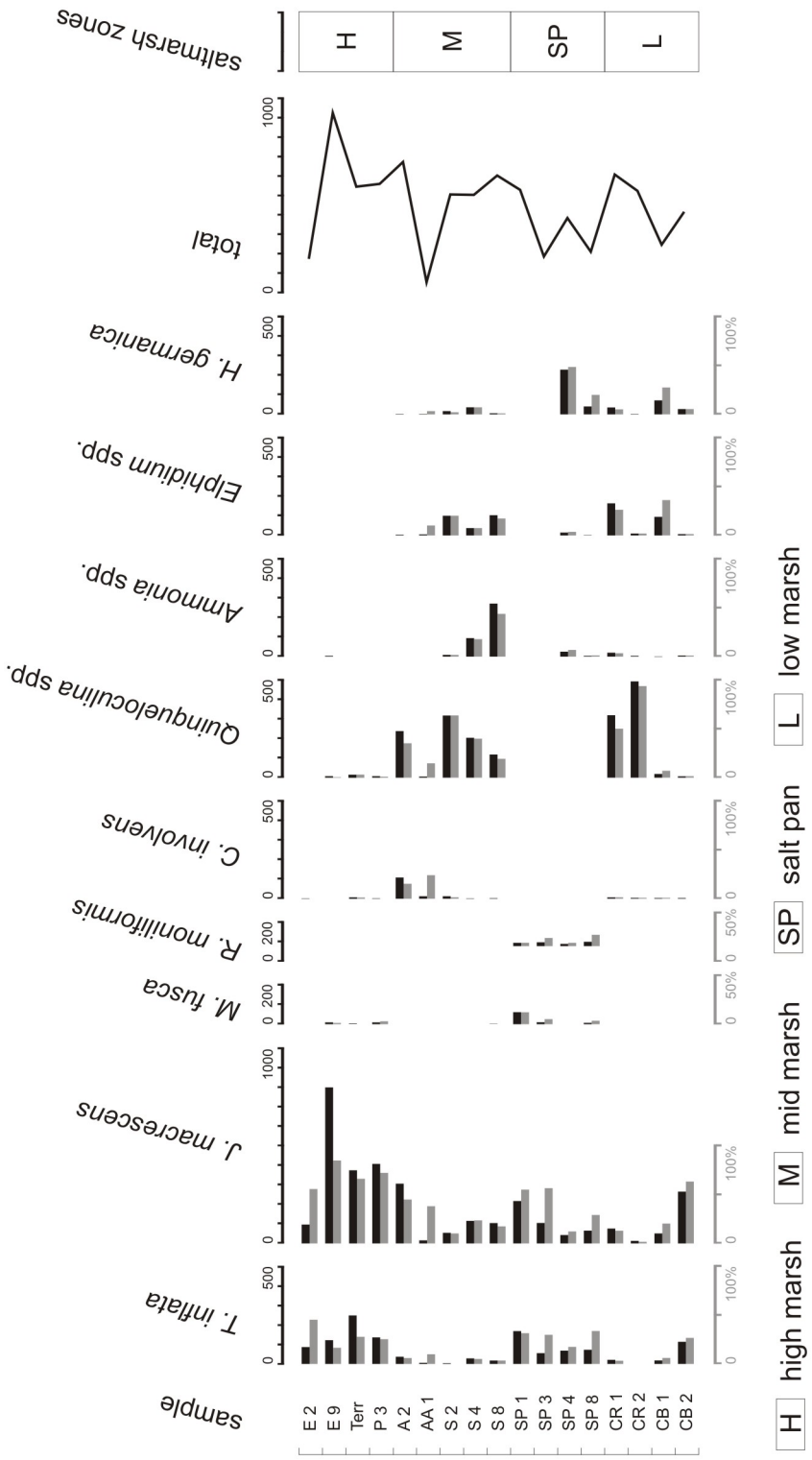


Figure 6.26.: All analysed Tollesbury saltmarsh surface samples are listed, except the ones used for the seasonal study. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total). The samples vary from high marsh (E 2 to P 3) over mid marsh (A 2, AA 1) to low marsh samples (S 2 to CB 2), indicated by the saltmarsh zones.

The samples E 2, P 3, SP 1 and SP 3 contain no Ostracoda. In the remaining 13 surface samples, 11 Ostracoda species belonging to 8 genera were found: *Cytherura gibba* (Mueller, 1785), *Cyprideis torosa* (Jones, 1850), *Hemicythere rubida* (Brady 1868), *Leptocythere baltica* Klie, 1929, *Leptocythere castanea* (Sars, 1866), *Leptocythere ciliata* Hartmann, 1957, *Leptocythere porcellanea* (Brady, 1869), *Loxoconcha elliptica* Brady, 1868, *Loxoconcha malcomsoni* Horne & Robinson, 1985, *Cytherois fischeri* (Sars, 1866), *Terrestricythere* sp., see table E.1 listing of absolute species numbers per sample. In figure 6.27, showing the Ostracoda species distribution per sample, the ones with a low abundance are grouped together (others): *C. gibba*, *H. rubida*, *L. elliptica* and *C. fischeri*.

The high marsh sample E 9 contains only four specimens of *L. baltica*, see figure 6.27. From the other high marsh sample Terr, which was collected from the plant roots of *Aster tripolium*, only two Ostracoda species were picked: *Terrestricythere* sp. (90%) and *L. porcellanea* (10%). The mid marsh samples A 2 and AA 1 both contain *L. malcomsoni* (33 and 17%), as well as, in A 2 also *L. castanea* and *L. ciliata*, and in AA 1 *L. porcellanea* were found. Low abundances of Ostracoda specimens were picked from the low marsh samples S 2, S 4, S 8, which contain predominantly *L.cythere porcellanea* and *L. malcomsoni*. The two salt pan samples SP 4 and SP 8 contain Ostracoda assemblages which are dominated by *C. torosa* (96 and 82%). *L. castanea* was found in both samples as well. The low marsh samples CR 1 and CR 2 both show an abundance of *L. malcomsoni* (16 and 56%) and *L. castanea* (66 and 11%). CR 1 also contains higher amounts of *L. porcellanea* (17%). In the lowest low marsh samples, CB 1 and CB 2, the Ostracoda assemblages are dominated by *L. castanea* (63 and 70%). Furthermore, *C. torosa* and *L. porcellanea* (6 and 24%) also appear in both samples, as well as *L. baltica* (28%) in CB 1.

At Tollesbury, *C. torosa* appears only in high abundance and alive in low marsh salt pans, see figure 6.27. Also, *L. castanea* is very abundant in the lowest marsh zone. Two rare Ostracoda were found as well, *Terrestricythere* sp. and *Loxoconcha malcomsoni*. Due to the seasonal study (chapter 6.2.2), *L. malcomsoni* was found mostly at the lower edge of the vegetated saltmarsh (CR = creek rim samples), possibly because of a narrow salinity tolerance (Horne & Boomer, 2000). *L. malcomsoni* appears to be restricted to marine or near-marine saltmarsh habitats and, as such, may be a valuable palaeoenvironmental and relative sea-level indicator in Pleistocene and Holocene assemblages. 37 adults of *Terrestricythere* sp. were found on the leaves and roots of *Aster tripolium*. So far, five species of the genus *Terrestricythere* have been found (Horne et al., 2004) in the NW Pacific, SE England and in the NE sea of Japan. From all locations it was found living in intertidal areas (creeks) and coarse sand with pebbles. This is now the first study site were a species of the genus *Terrestricythere* was found living on a saltmarsh. Also, noteworthy is here that *C. torosa* was found to be dominating the salt pans and was not found alive in other marsh zones.

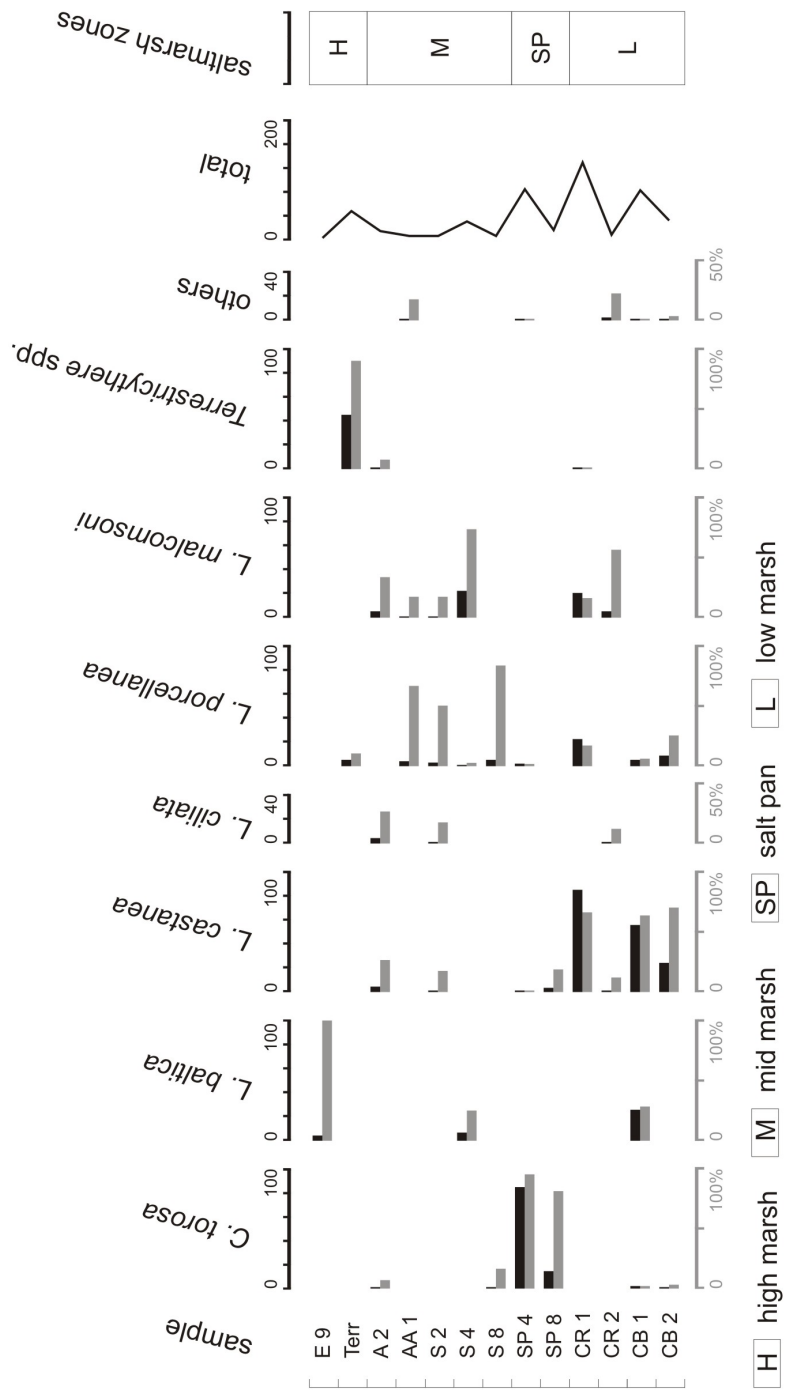


Figure 6.27.: All analysed Tollesbury saltmarsh surface samples are listed, except the ones used for the seasonal study. Per sample the absolute (black bars) and relative (grey bars) abundance of Ostracoda species are shown, including the absolute abundance of all picked specimens per sample (total). The samples vary from high marsh (E 9) over mid marsh (A 2, AA 1) to low marsh samples (S 2 to CB 2), indicated by the saltmarsh zones.

Tollesbury sediment cores

The 2.5 m deep sediment core TCE was extracted from the high marsh zone (*Elytrigia*) and divided into 25 samples (TCE 1 to TCE 25), each 10 cm long. In total, 3 905 Foraminifera specimens from 6 species belonging to 6 genera were picked: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina*

fusca (Brady, 1870), *Cornuspira involvens* (Reuss, 1850), *Ammonia* spp. and *Globigerina* sp., see table D.2 about absolute abundance of all species per sample.

Nearly all core samples contain agglutinated Foraminifera exclusively, exceptions are the top two core samples, each containing one specimen of *C. involvens* (TCE 1) and *Ammonia* spp. (TCE 2). And also from the samples TCE 14 and TCE 18, one test of *Globigerina* sp. each was picked, see figure 6.28. All other samples contain predominantly *T. inflata* and *J. macrescens*, as well as *M. fusca* with a low abundance of 1-3% (mostly in top 12 core samples). The top sample (TCE 1) contains 50% *T. inflata* and 50% *J. macrescens*. Sample TCE 2 below is dominated by the Foraminifera species *J. macrescens* (83%). It also contains 14% of *T. inflata*. The third sample (TCE 3), contains only *T. inflata*. The following samples, from 30 cm to 50 cm depth (TCE 4 and TCE 5), show higher abundances of *J. macrescens* (60 and 69%) than *T. inflata* (38 and 31%). Then, the samples ranging from 50 cm to a depth of 90 cm (TCE 6 to TCE 9), are dominated by *T. inflata* (max. 68%). And from a depth between 90 cm and 120 cm (TCE 10 to TCE 12), *J. macrescens* (max.65%) is dominating the Foraminiferal assemblages again. Then, the absolute abundance of all specimens per sample, from 120 cm to 200 cm depth (TCE 13 to TCE 20), shows a decrease with a minimum of 7 individuals in the same sample. The species *J. macrescens* also showed a decrease from 67 to 29%, and the abundance of *T. inflata* increases from 33 to 71%. At a depth of 190 cm (TCE 20), this trend is reversed up to a depth of 210 cm (TCE 21), showing an increase of *J. macrescens* (max. 63%) specimens and a decrease of *T. inflata* (max. 48%) tests. This trend is reversed again for the last 40 cm (TCE 22 to TCE 25), where the lowest sample contains 57% of *T. inflata* and 43% of *J. macrescens*. No Ostracoda were found in any core samples.

The clay content of the first two sediment cores (TCE, c II) is higher, whereas low amounts of sand was present (figure 6.28). This grain size proportion changes in the longest core (TC), where the clay content was the lowest of all cores. However, the silt fraction dominates all three sediment cores. Only the core TCE shows a whole marsh succession with gravel at the bottom, probably from the Pleistocene (British Geological Survey, 1832; Greensmith & Tucker, 1973), whereas the other two sediment cores did not show the beginning of the saltmarsh.

A 5 m deep sediment core TC was collected from the high-mid marsh zone (*Puccinellia*) at the outer area of the marsh plateau. It was divided into 10 cm long samples, leading to 50 core samples (TCE 1 to TCE 50). However, only every third sample was sorted through for microfossils. The 17 core samples contain 3 878 Foraminifera specimens from 6 species belonging to 6 genera: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Ammonia* spp., *Elphidium* spp. and *Haynesina germanica* (Ehrenberg, 1840), see table D.2 for absolute abundance of all species per sample.

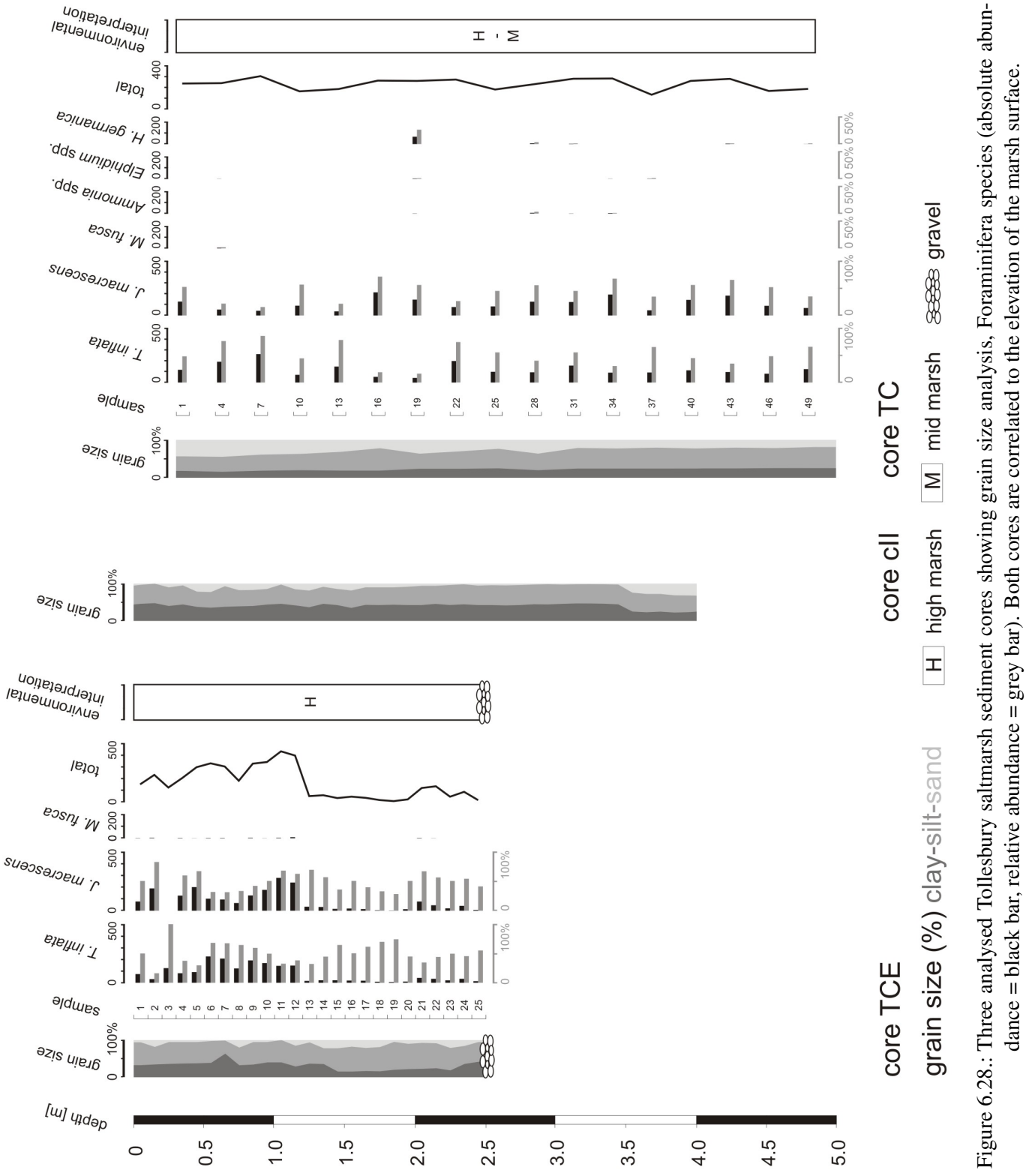


Figure 6.28.: Three analysed Tollesbury saltmarsh sediment cores showing grain size analysis, Foraminifera species (absolute abundance = black bar, relative abundance = grey bar). Both cores are correlated to the elevation of the marsh surface.

All core samples show a dominating agglutinated Foraminiferal assemblage, consisting of *T. inflata* and *J. macrescens*, see figure 6.28. With 5 specimens, also *M fusca* appears in sample TC 4 (30 to 40 cm depth). Low abundances (1-3%) of the calcareous forms *Ammonia* spp., *Elphidium* spp. and *H. germanica* were also found,

but were party dissolved. The only exception is the occurrence of *H. germanica* with 26% in sample TC 19 (180 to 190 cm depth). Similar to the TCE core, as described above, the *T. inflata* and *J. macrescens* species show a fluctuating trend. *J. macrescens* dominates the samples at a depth between 0-10 cm (TC 1), 90-100 cm (TC 10), 150-190 cm (TC 16 to TC 19), 330-340 cm (TC 34) and 390-460 cm (TC 40 to TC 46), with a maximum relative abundance of 81% at TC 16. The depths in between are dominated by *T. inflata*, which shows its highest abundance with 86%, at 60-70 cm depth (TC 7). No Ostracoda were found in any samples.

The Foraminiferal assemblages in both Tollesbury cores (TCE and TC) contain mostly the high marsh species *T. inflata* and *J. macrescens* (figure 6.28). This assemblage would indicate that the saltmarsh has been a high and high-mid marsh throughout its history. Neither core from Tollesbury contained a low marsh Foraminiferal assemblage with the exception of few samples which were partly dissolved. This absence of calcareous forms in the remaining samples may be due to the dissolution of the tests (chapter 8), but the presence of them in at least two core samples would suggest this was not the case. Although, they could have been transported there. The saltmarsh at Tollesbury had enough accumulation space due to a relative sea-level rise in combination of a land subsidence, so that the marsh was in equilibrium with the relative sea-level and does not show any migration. Therefore, both Tollesbury cores provide support for the role of relative sea-level rise in the formation of this saltmarsh (Hypothesis 2).

Additionally, three nearly 3.5 m deep sediment cores (EO, PO, SOC) extracted at Tollesbury saltmarsh (Janie, 2011) also show agglutinated (*T. inflata* and *J. macrescens*) dominating Foraminiferal assemblages throughout the cores, see figure 6.29. However, calcareous forms were also found in most core samples as well, see appendix F for absolute abundances of all Foraminifera species per sample. This would indicate, as mentioned above, that the lack of calcareous forms in some samples does not result from dissolution. All three cores, like the cores TCE and TC, provide support for the role of relative sea-level rise in the formation of this saltmarsh (Hypothesis 2).

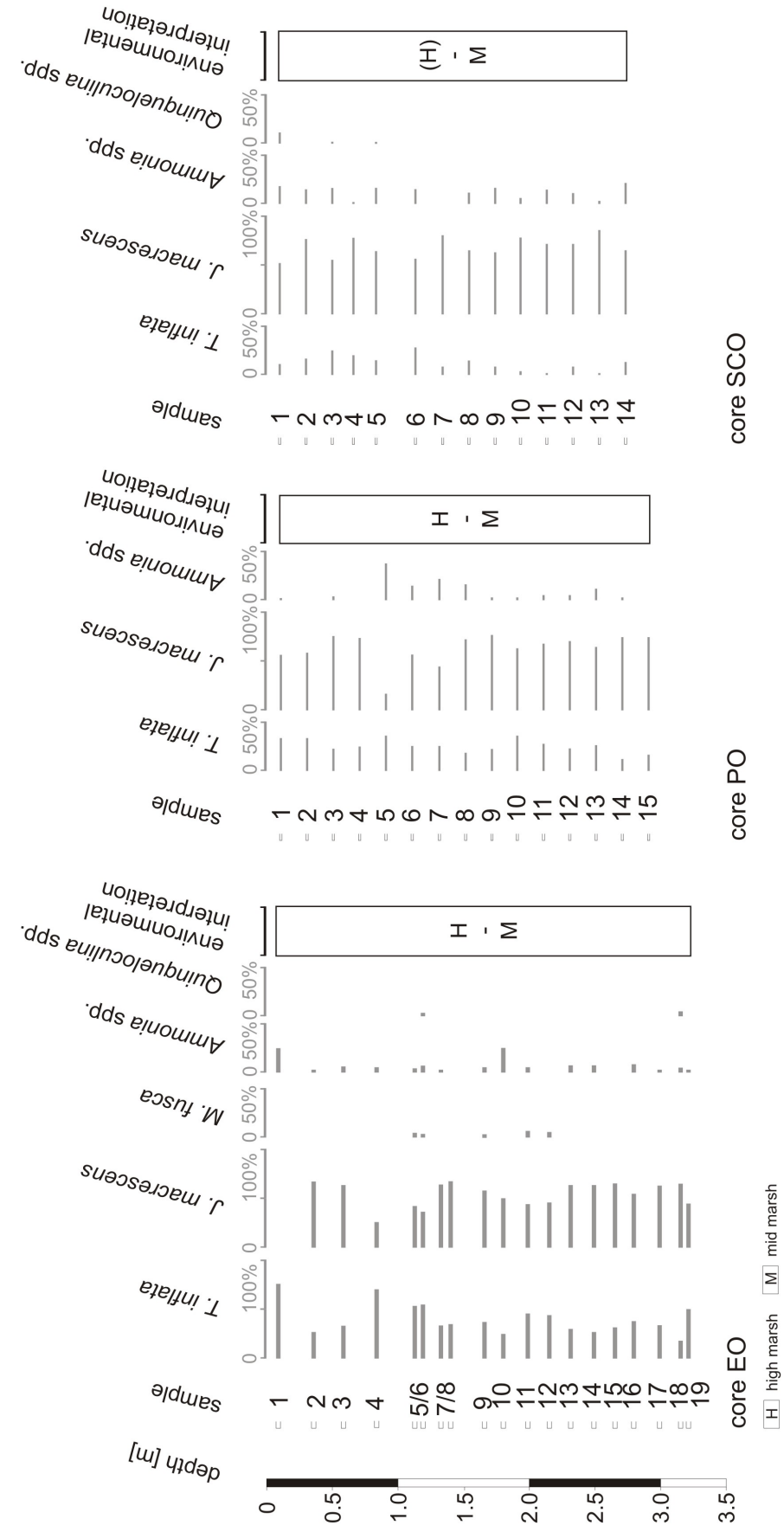


Figure 6.29.: Three saltmarsh sediment cores from Tollesbury with relative abundances (grey bars) for the most common Foraminifera species per core sample. The core EO was collected from the high marsh, core PO from high-mid and the core SOC from the low marsh (Janie, 2011).

Tollesbury PSA

From the 2.5 m (TCE) and 5 m (TC) deep sediment cores, particle size analyses (PSA) were conducted, see chapter 2.5 about the used methods. Furthermore, the 4 m long sediment core (c II), which was extracted for dating the sediment, see chapter 7, could also be used for a PSA.

The grain size of all 25 samples (TCE 1 to TCE 25) from the 2.5m long (TCE), high marsh core were measured. The sediment core consists of an average of 90% mud and 10% sand, with high clay content, coarse silt (14%) and less fine sand (4%), see figure 6.28. The core can be divided into three sections, where the first part (TCE 1 to TCE 14) contains 93% mud (37% clay) and 7% sand. The exception is sample TCE 7 with nearly 100% mud content (63% clay). The next section (TCE 15 to TCE 13) shows a higher sand fractions 14% and a lower mud content of 85% than the first one. The last part consists of the samples TCE 24 and TCE 25, which are similar to the first section with a 89% mud and 11% sand content. table G.1 shows the relative clay, silt and sand distribution for all 25 TCE samples. Also, all PSA data from the TCE core were plotted as grain size in µm (log scale) against the class weight in %, see figure 6.30. The 25 graphs show that the sediment of the core consists mainly of mud (clay and coarse silt) and shows only higher amounts of sand (fine sand) with decreasing depth (TCE 15 to TCE 23). Here, the sediment shows a better sorting compared to the other samples. The last two samples show similar results as those from the upper part of the core with the exception of sample TCE 7, which nearly consists of 100% mud. For a coloured version of these plots, see figure G.1.

The grain size of all 40 samples (cII 1 to cII 40) from the 4m long (c II) sediment core was measured. The sediment core consists of an average of 50% silt and 40% clay, with low contents of sand (10%), see figure 6.28. The core can be divided into four sections due to the changing amounts of the sand fraction. The first part (cII 1 to cII 2) contains nearly no sand (max. 2%), and max. 48% clay and max. 53% silt. The next section (cII 3 to cII 19) contains 2-22% sand, which shows a fluctuating trend with four lower sand fractions of 5% (cII 4), 6% (cII 7), 2% (cII 11) and 9% (cII 14). From sample cII 20 to cII 35, the sand fraction decreases from 8% to 1%. The last part (cII 36 to cII 40) shows the highest increase of the sand fraction, up to 31% at the bottom of the core. Also, here, the clay content also declines from 44 to 23%, the silt content less, with only 51 to 47%. The table G.1 shows the relative clay, silt and sand distribution for all 40 c II samples. Furthermore, all PSA data from the c II core were plotted as particle diameter in µm (log scale) against the class weight in %, see figure 6.31. The 40 graphs show that the sediment of the core consists mainly of mud (clay and coarse silt). Higher amounts of sand (fine sand) were measured for the lowest samples (cII 36 to cII 40), as well as the samples (cII 1 to cII 14). Here, the sediment shows a poorer sorting compared to the samples in-between (cII 15 to cII 34), which show a higher mud content. Exceptions are sample cII 7 and cII 11 which also show a higher mud content. The top four samples (cII I to cII 4) also show lower mud content than the samples below. For a coloured version of these plots, see figure G.2.

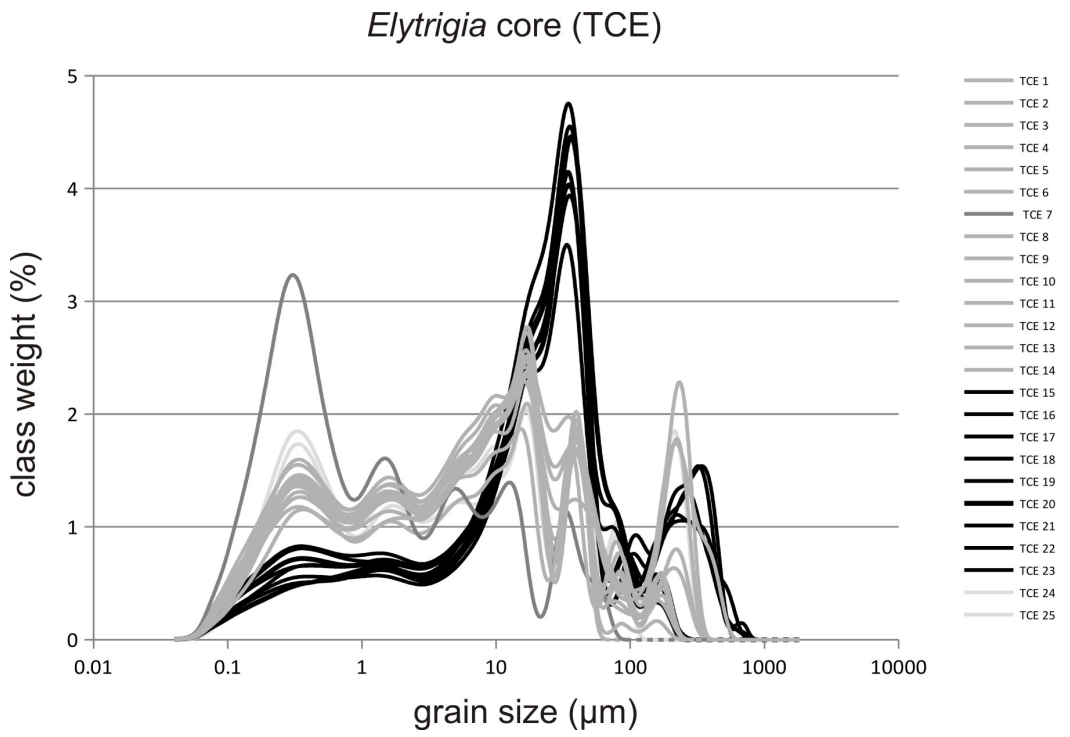


Figure 6.30.: PSA for the high marsh sediment core (TCE) from Tollesbury, showing the grains size distribution for all 25 samples. The sediment consists mainly of mud (clay and coarse silt). The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

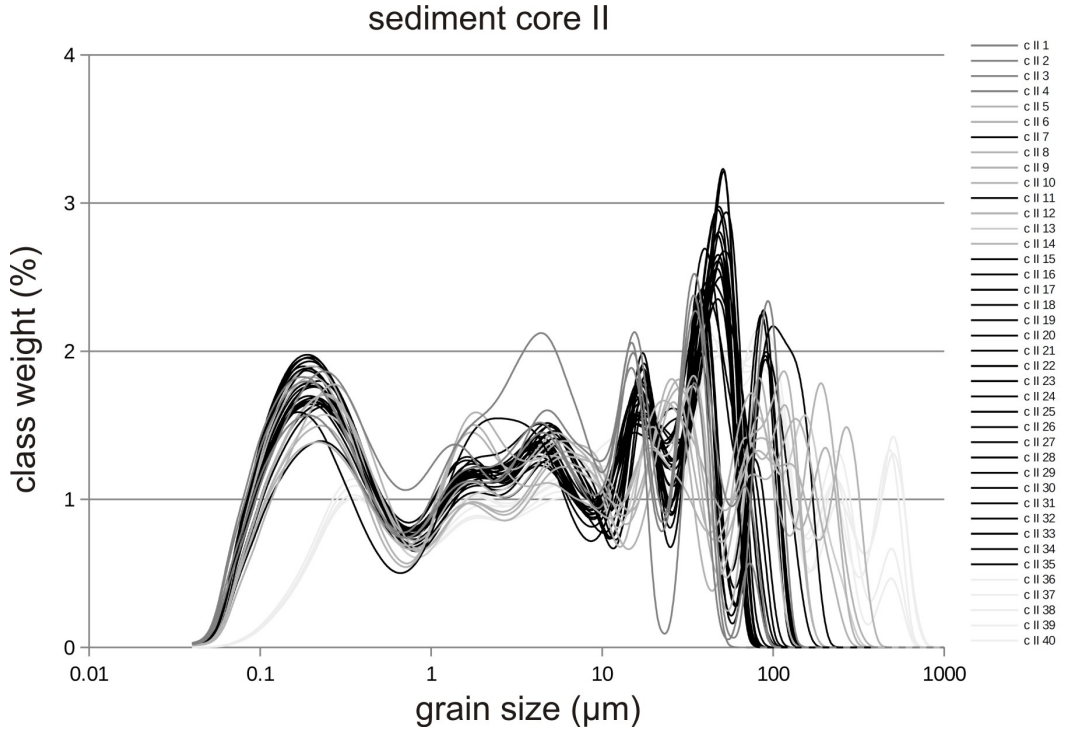


Figure 6.31.: PSA for the sediment core (c II) from Tollesbury, showing the grain size distribution for all 40 samples. The sediment consists mainly of mud (clay and coarse silt). The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

The grain size of every third sample from the 5 m deep high-mid marsh (*Puccinellia*) sediment core (TC) were measured, with a total of 17 samples (TC 1 to TC 49). The sediment core consists of an average of 50% silt, with low contents of 22% clay and 29% sand, see figure 6.28. The clay and sand content shows hardly any changes in its distribution throughout the core. For all samples, the measured clay content ranges between 16% and 25%, and the values of the silt fraction ranges from 39% to 56%. Only the sand shows a decreasing trend of its distribution for all core samples. The top contains 44% sand and decreases to 19% at the bottom of the core. In-between, it shows two peaks with both 36% sand at the samples TC 19 and TC 28. The table G.1 shows the relative clay, silt and sand distribution for all 17 TC samples. Also, all PSA data from the TC core were plotted as particle diameter in µm (log scale) against the class weight in %, see figure 6.32. The 17 graphs show that the sediment of the core consists mainly of mud (clay and coarse silt). Higher amounts of sand (fine sand) were measured from the lowest samples (TC 37 to TC 49), and upper samples (TC 1 to TC 7). Here, the sediment shows a poorer sorting compared to the other samples (TC 10 to TC 34). For s coloured version of these plots, see figure G.3.

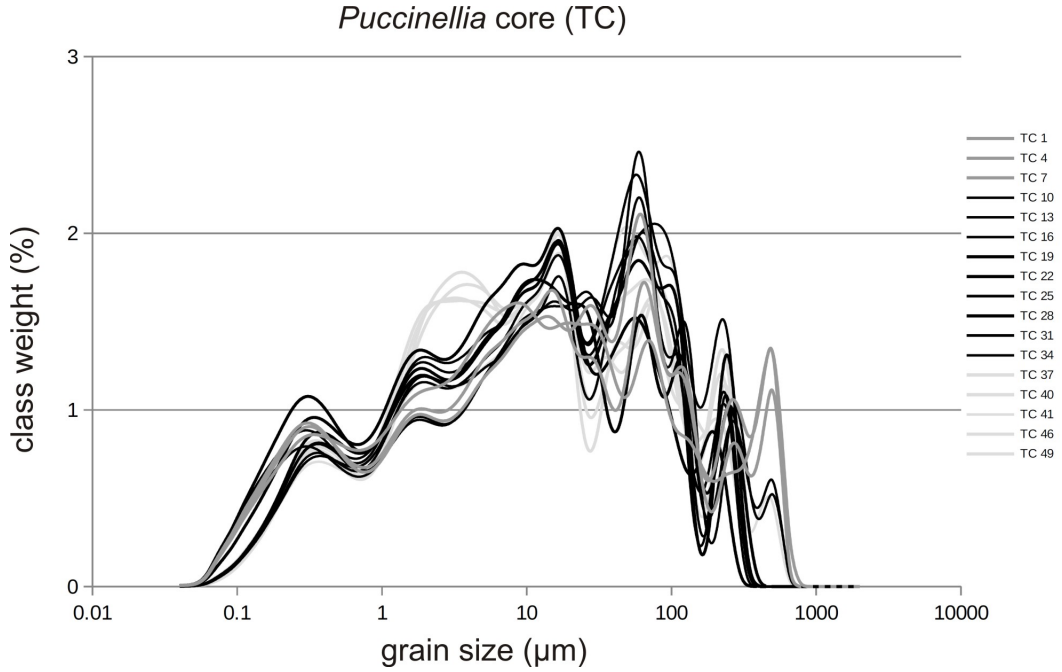


Figure 6.32.: PSA for the mid marsh sediment core (TC) from Tollesbury, showing the grain size distribution for all 17 samples. The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

The grain size analyses of three Tollesbury saltmarsh cores does not indicate any correlations between grain size changes and the Foraminiferal assemblages, see figure 6.28. However, the saltmarshes were more influenced by the sea than the River Blackwater, as can be seen by the poorly sorted sediment (figure 6.30, 6.31 and 6.32).

6.3.2. Two Tree Island saltmarsh samples

From the Two Tree Island saltmarsh, three surface samples and one sediment core (TCP) were collected. The 4 m deep sediment core is divided into 40 core samples (TCP 1 to TCP 40), however, only every third was analysed (13 in total). In nearly all surface and core samples Foraminifera and Ostracoda were found. An overview of the sampling location is shown in chapter 3.2.2.

Two Tree Island surface samples

The three saltmarsh surface samples contain 1 296 Foraminifera and 247 Ostracoda specimens. The samples were collected from the high (E 16), high-mid (P 6) and low marsh (S 6) zones. In all three surface samples, 11 Foraminifera species belonging to 11 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Cornuspira involvens* (Reuss, 1850), *Quinqueloculina* spp., *Ammonia* spp., *Elphidium* spp. and *Haynesina germanica* (Ehrenberg, 1840), *Cibicides* sp., *Lagena* spp. and *Glibigerina* sp., see table D.5 about absolute abundance of all Foraminifera species per sample, which is shown in figure 6.33. The latter three species are summarised as others, due to their low abundances.

The high marsh sample E 16 contains calcareous Foraminifera, where *H. germanica* (63%) dominates the assemblage. *Ammonia* spp., also occurs with 24%, see figure 6.33. The mid marsh sample P 6 contains a similar assemblage, with *H. germanica* (51%) showing the highest abundance. However, agglutinated forms also appear, with *T. inflata* (7%) and *J. macrescens* (13%). The low marsh sample S 6 is dominated by *Ammonia* spp. (67%), but still shows a high abundance of *H. germanica* (21%).

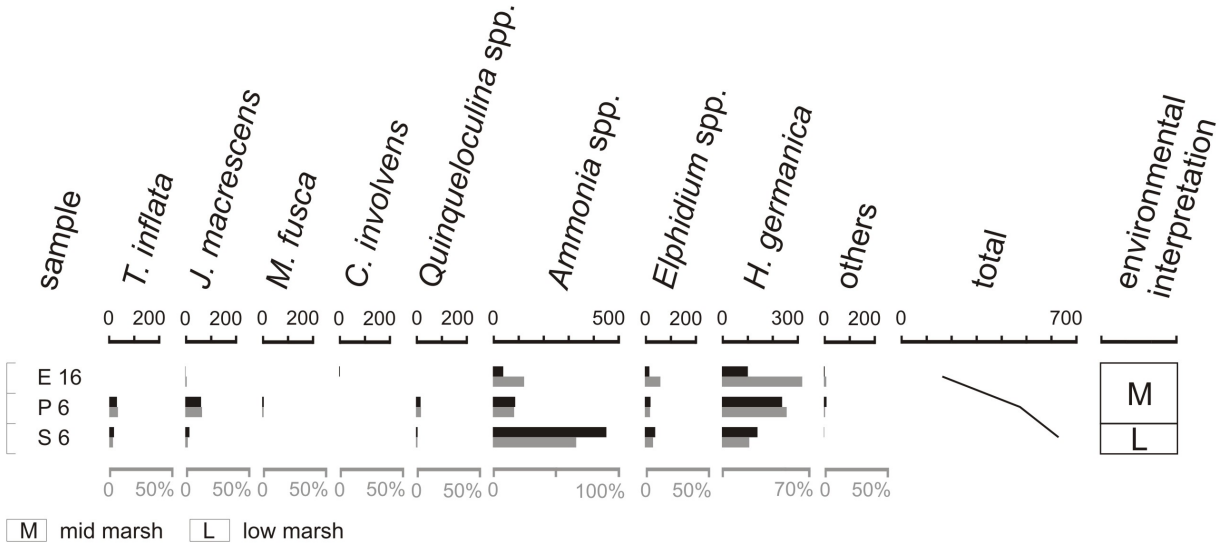


Figure 6.33.: Shown are all analysed Two Tree Island saltmarsh surface samples. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total).

The three surface samples from the Two Tree Island, show high abundances of the calcareous Foraminifera species *H. germanica*, as well as *Ammonia* spp., from high to low marsh. Hardly any agglutinated forms were present in the high marsh sample, only in the high-mid marsh (P 6), see figure 6.33. This could be due to the observed higher water content of the high marsh sample (E 16), where the water logged sediment probably resembles one from a lower elevation. This creates a more suitable habitat for low marsh Foraminifera species, like *H. germanica*.

In all three surface samples, 8 Ostracoda species belonging to 6 genera were found: *Cytherura gibba* (Mueller, 1785), *Semicytherura* sp., *Leptocythere castanea* (Sars, 1866), *Leptocythere ciliata* Hartmann, 1957, *Leptocythere porcellanea* (Brady, 1869), *Loxoconcha elliptica* Brady, 1868, *Cytherois fischeri* (Sars, 1866), *Paradoxostoma trieri* Horne & Whittaker, 1985, see table E.5 about absolute abundance of all species per sample.

Low Ostracoda abundances of *L. porcellanea* and *L. elliptica* were found in the high E 16 and high-mid marsh P 6 surface samples, see figure 6.34. Whereas, in the low marsh sample S 6, a high abundance of *L. castanea* with 68% and *L. ciliata* with 25% was found.

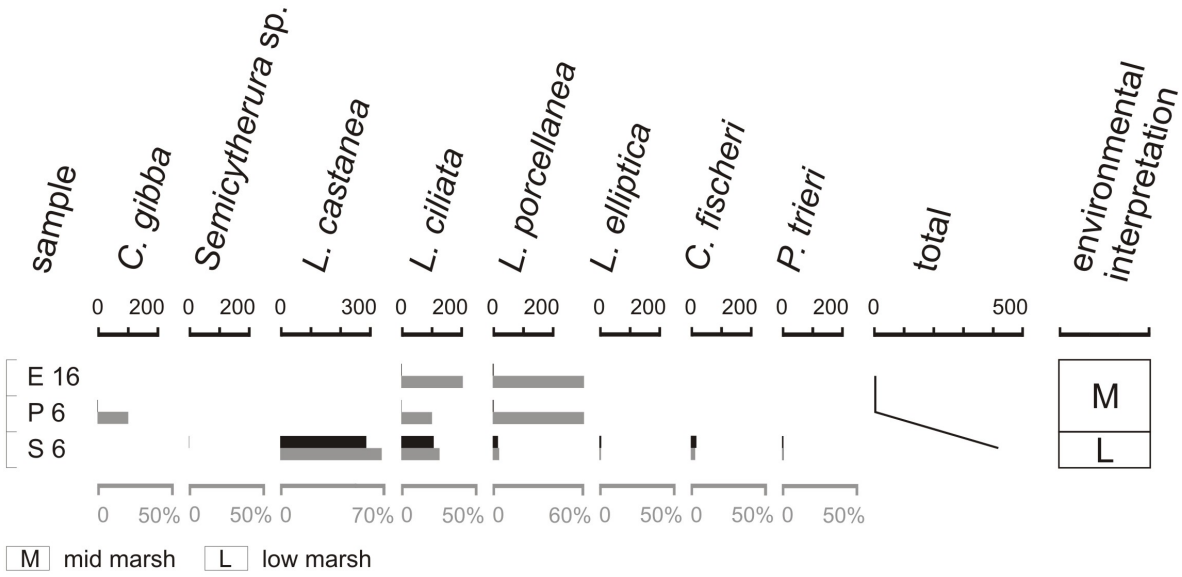


Figure 6.34.: All analysed Two Tree Island saltmarsh surface samples are listed. Per sample the absolute (black bars) and relative (grey bars) abundance of identified Ostracoda species are shown, including a curve representing the absolute abundance of all picked specimens per sample (line).

Two Tree Island sediment cores

The 13 sediment core samples (TCP) contain 5 143 Foraminifera and 1 183 Ostracoda specimens. The sediment core was collected from the high-mid marsh (*Puccinellia*) zone. In all analysed core samples, 12 Foraminifera species belonging to 12 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Cornuspira involvens* (Reuss, 1850), *Quinqueloculina* spp., *Am-*

monia spp., *Elphidium* spp., *Haynesina germanica* (Ehrenberg, 1840), *Asterigerinata* spp., *Cibicides* sp., *Lagena* spp. and *Glibigerina* sp., see table D.5 about absolute abundance of all Foraminifera species per sample, which is shown in figure 6.33. Here, the latter four species have been summarised as others, due to their low abundances.

The top core sample TCP 1, contains a Foraminiferal assemblage consisting of *T. inflata* (38%), *J. macrescens* (36%), *Quinqueloculina* spp. (18%), *Elphidium* spp. (15%), *H. germanica* (13%) and *Ammonia* spp. (64%), see figure 6.33. The next core sample contains predominantly *T. inflata* (53%), *J. macrescens* (42%). Then, the following 11 samples (TCP 7 to TCP 37) are dominated by the species *H. germanica*, which shows a decreasing trend (from 87 to 34%) with depth. The only other two Foraminifera species that occur in higher abundances in the these 11 samples are *Elphidium* spp. and *Ammonia* spp.. The latter shows an increasing trend with depth (ranging from 1 to 33%), except sample TCP 19. The core samples TCP 25, additional to the above mentioned species, contains *T. inflata* with 12%.

The 4 m deep sediment core (TCP) from the Two Tree Island saltmarsh contains a mix of agglutinated and calcareous Foraminifera at the top sample which indicates high-mid marsh conditions. Below, the *T. inflata* and *J. macrescens* predominating sample reflects high marsh. These agglutinated species decrease in abundance in the next sample at around 60 cm depth. However, calcareous forms dominated by *H. germanica* increase in abundance, indicating a mid marsh. The low marsh sample at 1 m depth consits of calcareous species only. For the remaining 3 m of the core, the Foraminiferal assemblage consists mainly of *H. germanica*, *Ammonia* spp. and *Elphidium* spp., which could be interpreted as mudflat conditions. The environmental interpretation leads to the conclusion that from the bottom to the top of the core, the Foraminiferal assemblages reflect a mudflat which is followed by a saltmarsh growth starting at 1.5 m depth from low to high marsh. Given that a known relative sea-level rise exists for the Thames Estuary (Pye, 2000; Shennan & Horton, 2002), the saltmarsh at the top of the core, therefore keeps pace through facilitation succession (Hypothesis 1).

A second core (4 m deep) from the same saltmarsh at Two Tree Island was extracted and analysed as part of a master project (Palmisano, 2010). The Foraminifera also show a change from a calcareous to an agglutinating dominating assemblage for the top metre, see appendix F.2 for the absolute abundance of Foraminifera species per core sample. Due to a higher sampling resolution, the development of the marsh can be better observed, where the marsh growth would start at around 1.5 m depth (figure 6.36). The samples below indicate mudflat conditions (calcareous Foraminifera), the found agglutinated specimens showed traces of transportation (abrasion). The saltmarsh in this core began as low marsh, indicated by the Foraminiferal assemblage dominated by *H. germanica* as well as the presence of *J. macrescens* starting at 1 m depth. Then the marsh changes to a mid marsh (samples 4) and continues as a high-mid marsh core, reflected by a *T. inflata* and *J. macrescens* assemblage for the top three samples and hardly calcareous specimens. This marsh succession from low to high marsh supports Hypothesis 1.

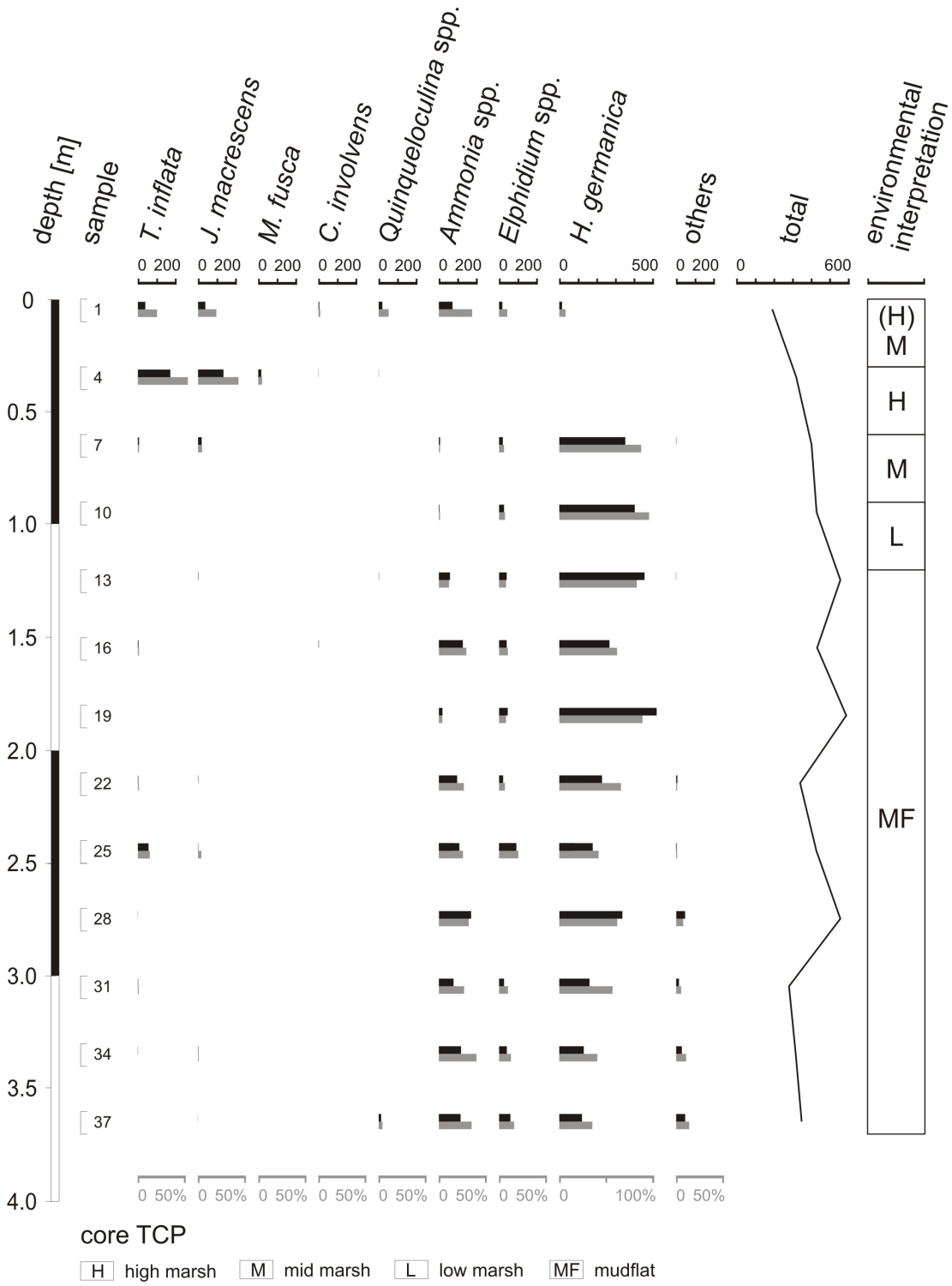


Figure 6.35.: The 4 m deep Two Tree Island high-mid marsh sediment core (TCP). Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens (total).

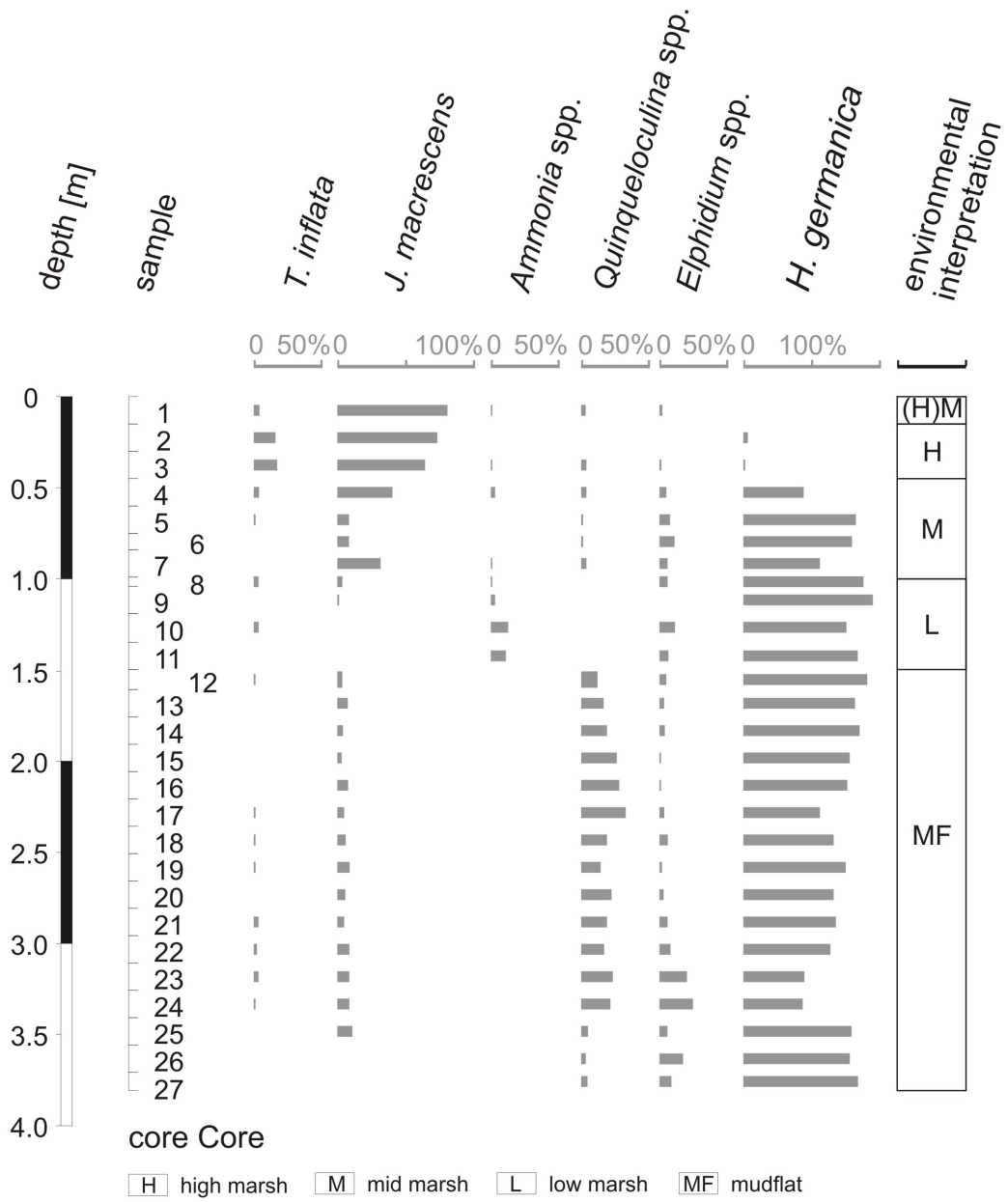


Figure 6.36.: A nearly 4 m deep saltmarsh sediment core from Two Tree Island (Core), showing the relative abundance (black bars) of the most common Foraminifera species per core sample.The core was extracted from a mid marsh zone (Palmisano, 2010).

The core sample TCP 4 contains no Ostracoda. In the remaining 12 samples, 28 Ostracoda species belonging to 19 genera were found: *Pontocythere elongata* (Brady, 1868), *Cytherura gibba* (Mueller, 1785), *Cyprideis torosa* (Jones, 1850), *Cytheropteron* cf. *depressum* Brady & Norman, 1889, *Cytheropteron* cf. *monoceros* Bonaduce, Ciampo & Masoli, 1976, *Cytheropteron punctatum* Brady, 1868, *Hemicytherura* cf. *cellulosa* (Norman, 1865), *Semicytherura* sp., *Hemicythere villosa* (Sars, 1866), *Heterocythereis albomaculata* (Baird, 1838), *Leptocythere castanea* (Sars, 1866), *Leptocythere porcellanea* (Brady, 1869), *Leptocythere psammophila* Guillaume, 1976,

Hirschmannia viridis (O. F. Müller, 1785), *Loxoconcha elliptica* Brady, 1868, *Palmoconcha laevata* (Norman, 1865), *Hiltermannicythere* cf. *emaciata* (Brady, 1867), *Xestoleberis* sp. *Hemicytherura* sp., *Microcytherura* sp., *Aurila woutersi* Horne, 1986, *Leptocythere ciliata* Hartmann, 1957, *Loxoconcha rhomboidea* (Fischer, 1855), *Cytherois fischeri* (Sars, 1866), *Cytherois* sp., *Paradoxostoma ensiforme* Brady, 1868, *Paradoxostoma trieri* Horne & Whittaker, 1985, *Carinocythereis* cf. *whitei* (Baird, 1850) and *Xestoleberis* sp., see table E.5 about absolute abundance of all species per sample. In figure 6.37, the latter 10 Ostracoda species have been summarised as others due to their low abundances per sample. Furthermore, all species listed here belonging to the genus *Cytheropteron* were also combined to *Cytheropteron* spp..

The first three core samples (TCP 1 to TCP 7) show low overall Ostracoda abundances, with 9 to 35 specimens per sample, see figure 6.37. The top sample is dominated by *H. albomaculata* (89%), and in the next two samples *L. porcellanea* (83 and 53%) dominates the Ostracoda assemblages. The sample TCP 10 contains a similar assemblage as the one in sample TCP 7. In the next two samples (TCP 13 and TCP 16) the Ostracoda *L. castanea* shows a higher abundance with 43 to 48%, but *L. porcellanea* (53%) is still the dominating species in sample TCP 13. The core sample TCP 19 contains an Ostracoda assemblage consisting only of: *L. castanea* (7%), *L. porcellanea* (14%) and *C. torosa* (79%). The latter one shows here its highest abundance of the all TCP core samples. In sample TCP 22, low abundances of *P.cythere elongata*, *H. viridis* and *L. elliptica* were found, but they continue to be present in the deeper sediment samples as well. However, the predominant species are still *L. castanea* (43%), *L. porcellanea* (35%) and *C. torosa* (10%). Sample TCP 25 contains mostly *L. porcellanea* (37%), *L. elliptica* (26%), *C. torosa* (16%) and *L. castanea* (9%). A similar assemblage can be found in sample TCP 28, but three more species appear with higher abundances as well compared to all previous core samples: *P. elongata* (10%), *Semicytherura* sp. (9%) and *H. viridis* (13%). The next sample (TCP 31) contains a similar Ostracoda assemblage as sample TCP 28, only with a lower abundance of *L. castanea* (5%) and a higher one of *Xestoleberis* sp. (20%). The assemblages found in the two deepest samples (TCP 34 and TCP 37) of the TCP core, are alike, with a very diverse range of low Ostracoda species abundances: *P. elongata* (7-5%), *C. torosa* (7-6%), *Cytheropteron* spp. (7-6%), *Semicytherura* sp. (8-6%), *L. psammophila* (14-20%), *H. viridis* (9-8%) and *L. elliptica* (each 10%). Additional, the sample TCP 34 contains *L. porcellanea* (18%), and sample TCP 37 *L. castanea* (13%). It is to mention that from the lower abundances of species, which start to appear in sample TCP 22 (figure 6.37), mostly juvenile valves were found. For more detailed description of each species distribution, can be found in chapter 5.2.

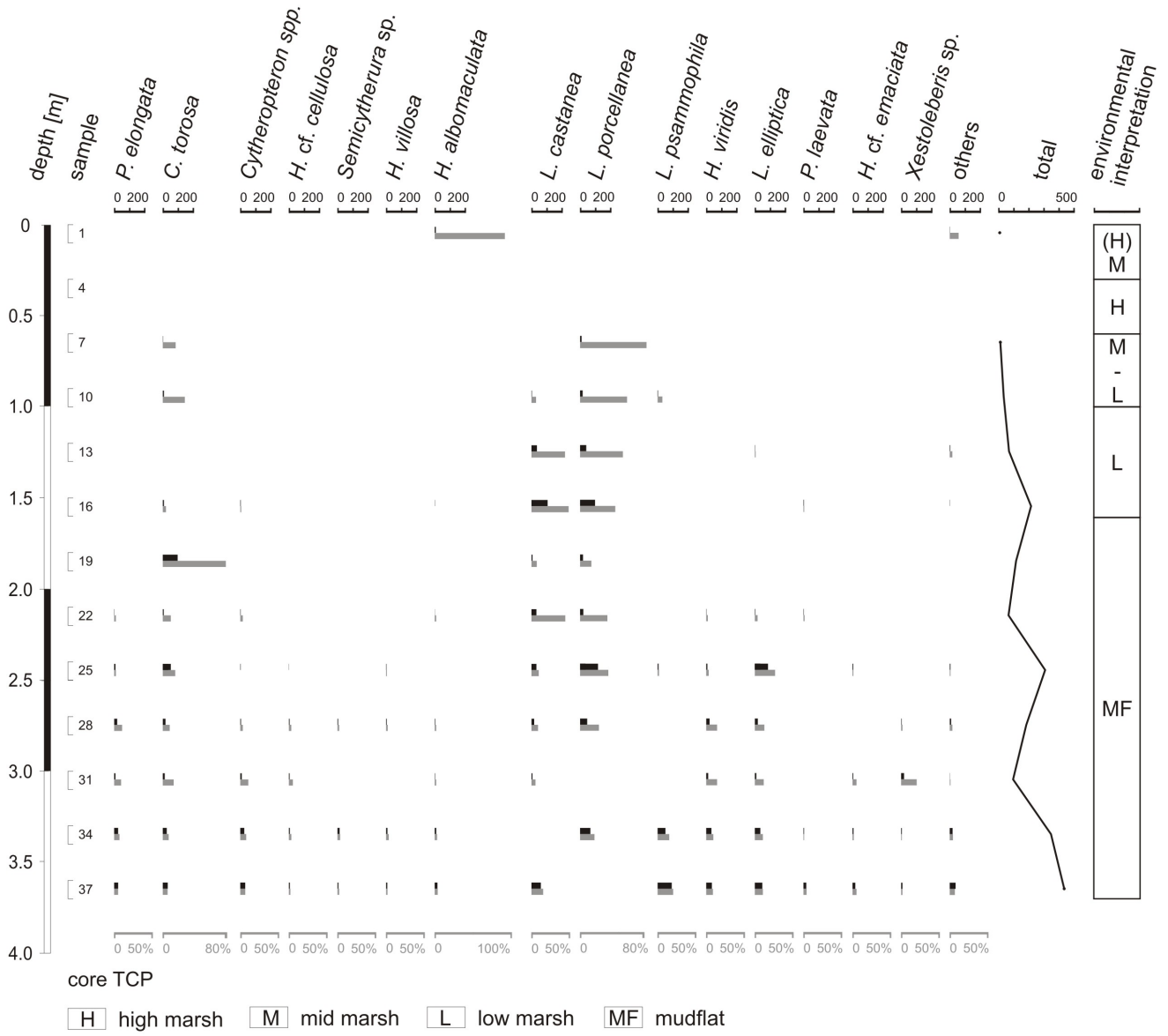


Figure 6.37.: The 4 m deep Two Tree Island high marsh sediment core (TCP), showing the absolute (black bars) and relative (grey bars) abundance of Ostracoda species are shown, including the absolute abundance of all picked specimens per sample (total).

The Ostracoda from the Two Tree Island core (figure 6.37) can be used to distinguish not only the marsh zones, but the development of the Thames Estuary. Where the first top metre of the sediment core can be identified as high to mid(-low) saltmarsh, due to the either the absence of Ostracoda or presence of a low abundance of *L. castanea* and *L. porcellanea*. The top half of the second metre of the core represents a low marsh environment, because of a higher abundance of saltmarsh Ostracoda *L. porcellanea* and *L. castanea* compared to the top metre. The higher abundance of *C. torosa* for the second half can be interpreted as the start of the mudflat, because this species was found either only in salt pans (Tollesbury) or on the mudflat as well (Kyleakin). The increasing abundance of

juvenile valves indicate an environmental change at around 2 m depth. There, the diversity of Ostracoda species increases towards the bottom of the core, and a higher number of valves were observed in the three bottom most samples, indicating a high energy thanatocoenosis (Boomer et al., 2003). This means that a development from an inner to an outer estuarine can be assumed. Noteworthy is also that the Foraminiferal assemblage from the same core show a similar environmental development (figure 6.35 and 6.36). The environmental interpretation for this core indicates that from the bottom to the top of the core, the Ostracoda assemblages reflect probably an open estuary (marine assemblage) that changes (species diversity decreases) to a more sheltered estuary only to be replaced by a saltmarsh (top three samples with saltmarsh assemblage).

6.3.3. Gann saltmarsh samples

Four surface samples and three sediment cores were collected and analysed from the Gann saltmarsh. The core T 2 and T 3 is each 40 cm deep and the core T 5 50 cm deep. In all samples Foraminifera were found, and the latter two also contain Ostracoda. An overview of the sampling location is shown in chapter 3.2.4.

Gann surface samples

The four saltmarsh surface samples contain 2 576 Foraminifera and 247 Ostracoda specimens. The samples were collected from the high (E 1), high-mid (P 1), mid (A 1) and low marsh (S 1) zones. In all four surface samples, 9 Foraminifera species belonging to 9 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Reophax moniliformis* Siddall, 1886, *Cornuspira involvens* (Reuss, 1850), *Quinqueloculina* spp., *Ammonia* spp., *Elphidium* spp. and *Haynesina germanica* (Ehrenberg, 1840), see table D.6 about absolute abundance of all species per sample.

The high marsh sample E 1 is dominated by *T. inflata* with 92%, see figure 6.38. The high-mid marsh sample P 1 contains high amounts of *T. inflata* (40%) and *J. macrescens* (43%), as well as a low abundance of *M. fusca* (11%). The mid marsh sample A 1 is dominated by *J. macrescens* (56%), but higher abundances of *M. fusca* (11%) and *C. involvens* (15%) also occur. The Foraminiferal assemblage in the low marsh sample S 1 consists of *T. inflata* (16%) and *J. macrescens* (13%), *Elphidium* spp. (24%) and *H. germanica* (35%).

The surface samples from the Tollesbury and Gann saltmarsh sites show a decreasing trend in agglutinated Foraminifera (*T. inflata* and *J. macrescens*), and an increasing trend in calcareous species (*Quinqueloculina* spp., *H. germanica*, *Ammonia* spp., *Elphidium* spp.) from high (*Elytrigia*) to low (*Salicornia*) marsh including the creek sediment, see figure 6.26 and 6.38. The difference in the Foraminiferal assemblages between those locations is the higher abundance of *Quinqueloculina* spp. and *H. germanica* in Tollesbury. Whereas in Gann more *M. fusca* and *C. involvens*, as well as similar amounts of *Elphidium* spp. could be identified. This could be due to the dependency of Foraminifera species with varying sediment composition (Gupta, 1999), which is also true for

Ostracoda (Barker, 1983). The surface samples in Wales are more enriched in sand than those in Tollesbury, see PSA analyses of sediment cores (figure 6.28 and 6.40). The reason for this is the geology: Pembrokeshire consists of old Devonian bedrock with Old Red Sandstone, whereas in Essex younger Mesozoic and Cenozoic rocks with the London Clay are found (British Geological Survey, 1832).

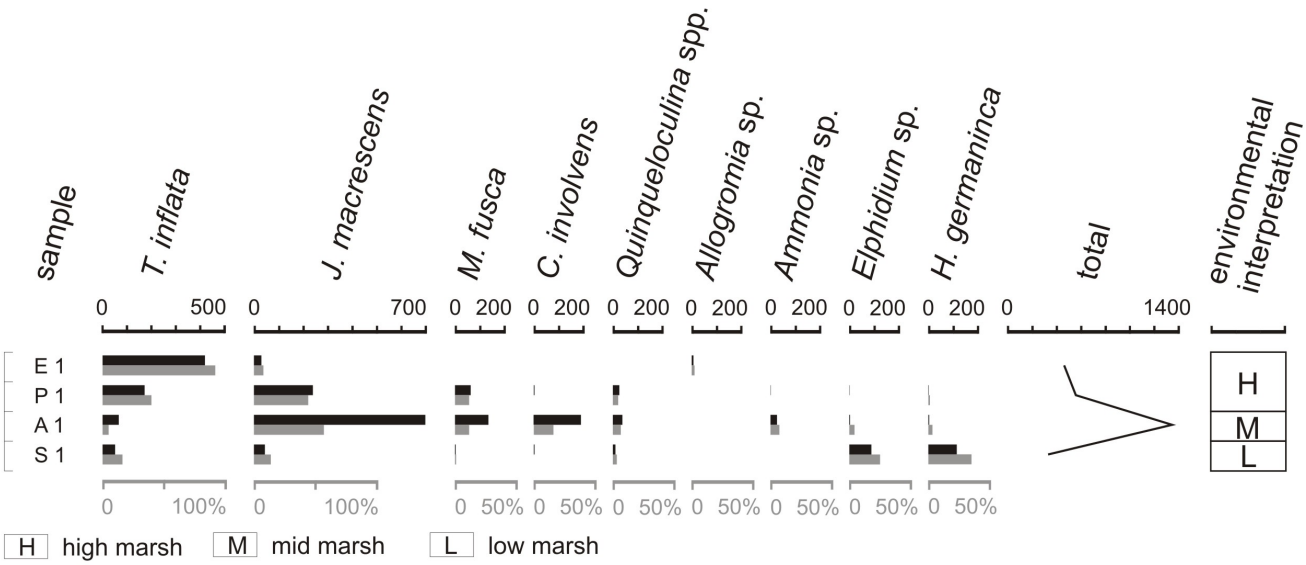


Figure 6.38.: From the Gann saltmarsh, four surface samples were analysed. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total).

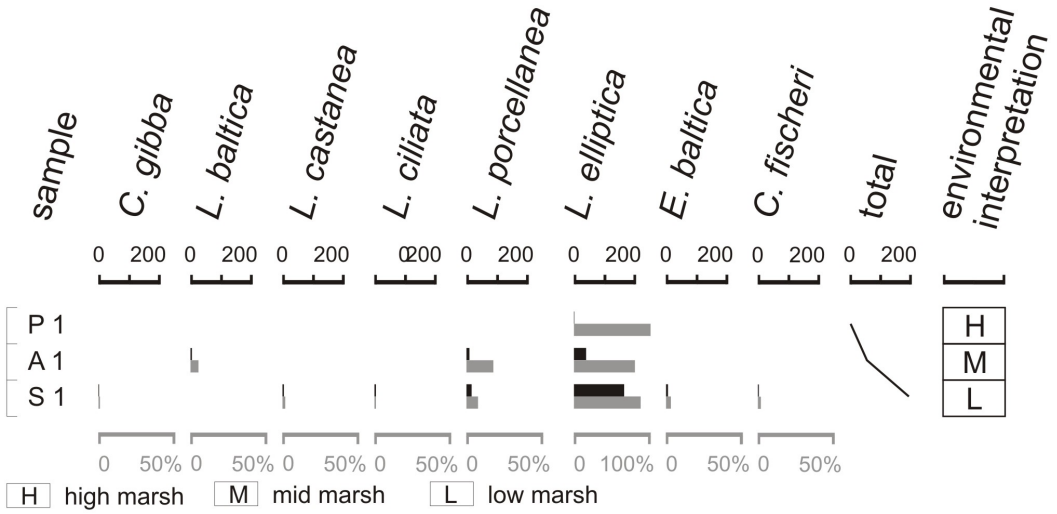


Figure 6.39.: From the Gann saltmarsh, four surface samples were analysed. Per sample the absolute (black bars) and relative (grey bars) abundance of Ostracoda species are shown, including the absolute abundance of all picked specimens per sample (total).

The sample E 1 contains no Ostracoda. In the remaining three surface samples, 8 Ostracoda species belonging to 5 genera were found: *Cytherura gibba* (Mueller, 1785), *Leptocythere baltica* Klie, 1929, *Leptocythere castanea* (Sars, 1866), *Leptocythere ciliata* Hartmann, 1957, *Leptocythere porcellanea* (Brady, 1869), *Loxoconcha elliptica* Brady, 1868, *Elofsonia baltica* (Hirschmann, 1909) and *Cytherois fischeri* (Sars, 1866), see table E.8 which lists the absolute abundance of all Ostracoda species per sample.

In all three surface samples, the Foraminifera species *L. elliptica* dominates all assemblages, ranging from 100 to 85%, see figure 6.39. The mid (A 1) and low marsh (S 1) samples also contain low abundances of *L. porcellanea* (18 and 7%). The remaining Ostracoda species, if present, show a low abundance with less than 5%.

Gann sediment cores

The 13 saltmarsh core samples contain 3 291 Foraminifera tests. The core T 3 was sampled from a high-mid marsh, and the core T 4 was extracted from a low marsh zone. The core T 3 is divided into four samples (T3 1 to T3 4), and core T 4 into five samples (T4 1 to T4 5). In all core samples, 9 Foraminifera species belonging to 9 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Cornuspira involvens* (Reuss, 1850), *Quinqueloculina* spp., *Ammonia* spp., *Elphidium* spp., *Haynesina germanica* (Ehrenberg, 1840) and *Allogromia* sp., see table D.6 about absolute abundance of all species per sample.

The found Foraminiferal assemblages in all samples (T2 1 to T2 4), from the high marsh core T 2, are dominated by *J. macrescens* (68 to 91%), see figure 6.40. The only other species which was found also in all samples from the T 2, was *T. inflata* with low abundances of 9 to 32%. All samples (T3 1 to T3 4) of the sediment core T 3 show a Foraminiferal assemblage which is dominated by *J. macrescens* (53 to 85%), see figure 6.40. *Quinqueloculina* spp. also appears with low abundances of 6 to 24% in the top three samples, as well as *Elphidium* spp. (4 to 7%). *T. inflata* and *H. germanica* were also found in all samples from the T 3 core. The Foraminiferal assemblages identified in all low marsh core samples (T4 to T4 5) are dominated by *J. macrescens* (61 to 87%), see figure 6.40. The species *T. inflata*, *Quinqueloculina* spp., *Elphidium* spp. and *H. germanica* appear also in all T 4 core samples, with less than 14%.

The core samples contain high amounts of coarse to fine silt which dominates the grain size distribution of all cores (figure 6.40). The lowest sample of core T4 contains the highest amount of sand of all samples. The clay content is low in all cores. Also, all cores reached the bedrock underneath the sediment. The grain size succession shows no correlation between its changes and the Foraminiferal assemblages.

The core samples from the Gann are all dominated by *J. macrescens*, which is identified as a high marsh species for this area. The high marsh zone can be identified throughout all three cores (T 2, T 3, T 4), see figure 6.40. The presence of *T. inlfata* as the only additional species in all marsh cores can be interpreted as the core samples

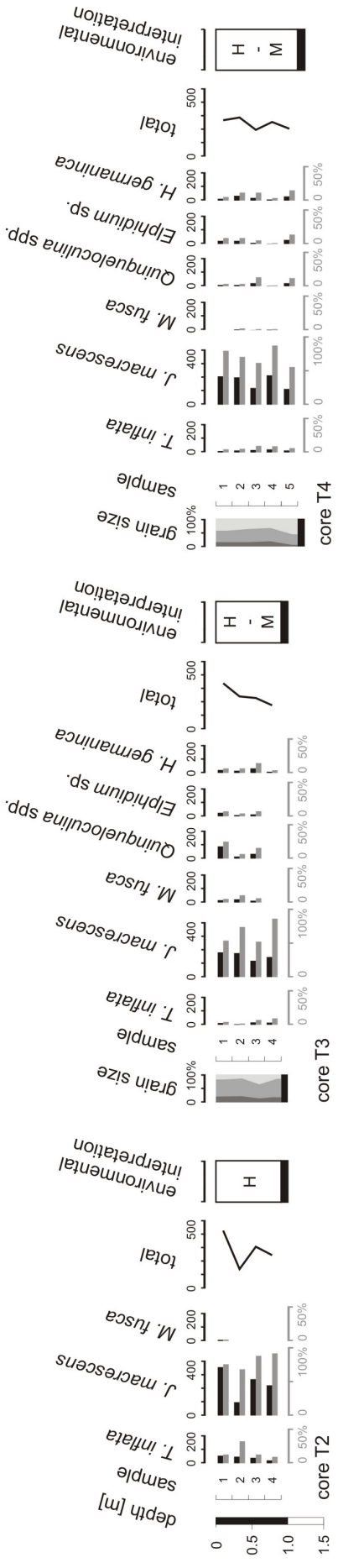


Figure 6.40.: Three saltmarsh sediment cores from Gann. Per sample the absolute (black bars) and relative (grey bars) abundance of the most common Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total). Also the grain size for two cores are also shown.

showing a closer relationship to a high marsh zone. The mid (T 3) and mid-low marsh (T 4) cores also contain calcareous Foraminifera, but with low abundances. Also, *T. inflata* was still found in all core samples from the cores T 3 and T 4, which indicates high marsh conditions throughout all samples. In conclusion, the dominating lower high marsh species *J. macrescens* indicates no changes in zonation which means that the marsh began as a high marsh and is keeping pace with the relative rising sea-level in this area as predicted by Hypothesis 2.

The sediment core T 2 contains no Ostracoda. The remaining nine core samples contain 23 specimens of 2 Ostracoda species belonging to 2 genera: *Loxoconcha elliptica* Brady, 1868 and *Cytherois fischeri* (Sars, 1866), see table E.8 which lists the absolute abundance of all Ostracoda species per sample.

The first three samples (T3 1 to T3 3) of the T 3 core contain low abundances of *L. elliptica*, ranging from 1 to 9 specimens per sample, see figure 6.41. All samples (T4 1 to T4 5) of the low marsh core T 4 also contain *L. elliptica*, only in the sample T4 2 one specimen of *C. fischeri* was also found.

The Ostracoda abundance in the high-mid marsh core (T 3) could indicate a marsh succession from high to mid marsh from the bottom to the top of the core (figure 6.41). This can be interpreted with the absence of *L. elliptica* in the lowest sample and an increase of its abundance towards the top sample. The low marsh core (T 4) in contrast contains only a low abundance of Ostracoda throughout, indicating a mid marsh, because for low marsh a higher abundance of Ostracoda would be necessary. However, due to the very low abundance of Ostracoda valves in the cores, the marsh succession as shown with the Foraminiferal assemblages is probably more accurate.

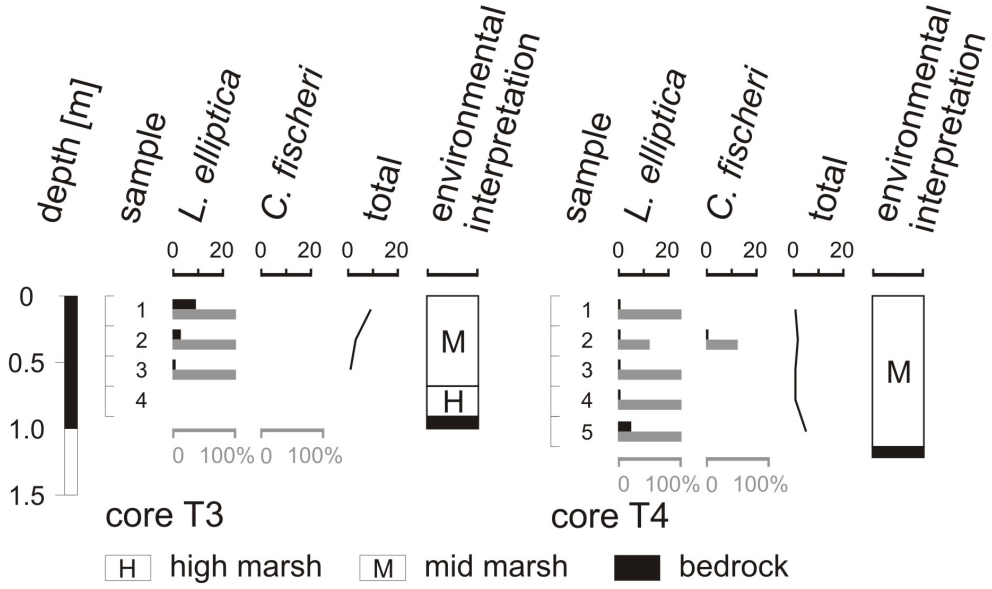


Figure 6.41.: Two saltmarsh sediment cores from Gann. Per sample the absolute (black bars) and relative (grey bars) abundance of Ostracoda species are shown, including the absolute abundance of all picked specimens per sample (total).

Gann PSA

For the high-mid marsh *Puccinellia-Atripex* (T 3) and low marsh *Salicornia* (T 4) sediment cores, enough sediment material was available to run a particle size analysis (PSA). No sediment was left of the *Puccinellia* core (T 2) for a PSA. From each core four samples were measured, see chapter 2.5 about methods.

From the first core (T 3), the four samples show a high amount of mud (64-86%) and less sand (13-35%), see figure6.40. The mud consists mainly of coarse to medium silt (13-18%) and clay (13-22%). Whereas, the sand fraction consists of medium (1-6%) to fine sand (4-17%). Sample 3 shows the highest amount of fine sand (35%) and the lowest of mud (64%). The table G.2 shows the relative clay, silt and sand distribution for all 4 T 3 samples. Furthermore, all PSA data from the T 3 core were plotted as particle diameter in µm (log scale) against the class weight in %, see figure 6.42. The top samples T3 1 and T3 2 contain over 80% clay, compared to the lower samples (T3 3 to T3 4). Sample T3 3 contains with 17% the highest amount of fine sand of all samples. For a coloured version of these plots, see figure G.4.

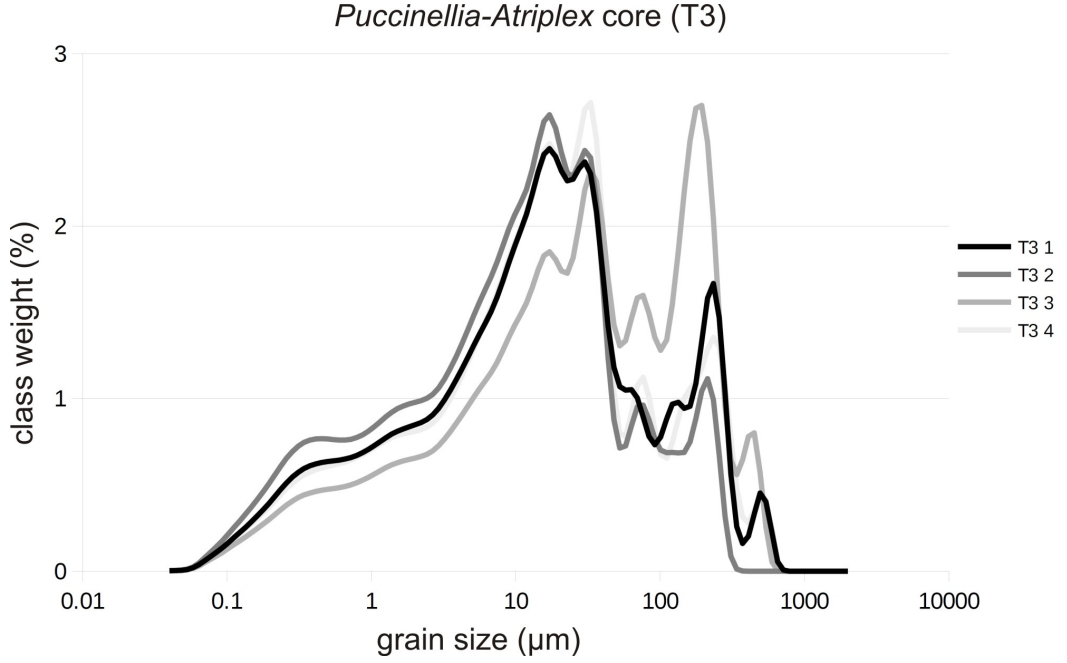


Figure 6.42.: Particle size analysis for the *Puccinellia-Atriplex* core (T3) from Gann. Four samples were measured (T3 1, T3 2, T3 3, T3 4) which contain high amount of coarse to fine silt and mud. The exceptions are sample P-A/3 where the sand fraction is nearly similar or higher as the mud fraction. The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

The *Salicornia* core (T 4) shows higher values of mud (69-77%) than sand (22-30%), with the exception of the last sample where the sand fraction (57%) is higher than the mud fraction (42%), see figure6.40. Furthermore, the mud consists also mainly of coarse (14%) to medium (9-14%) silt and clay (6-19%). The sand shows high

amounts of the medium (4-13%) and fine sand fraction (10-32%). The table G.2 shows the relative clay, silt and sand distribution for all 4 T 4 samples. Also, all PSA data from the T 4 core were plotted as particle diameter in µm (log scale) against the class weight in %, see figure 6.43. The top three samples T4 1 to T4 3 contain over 66% mud, compared to the lowest samples (T4 4) with 42%. The sample T4 4 also contains with 32% the highest amount of fine sand from all samples. For a coloured version of these plots, see figure G.5.

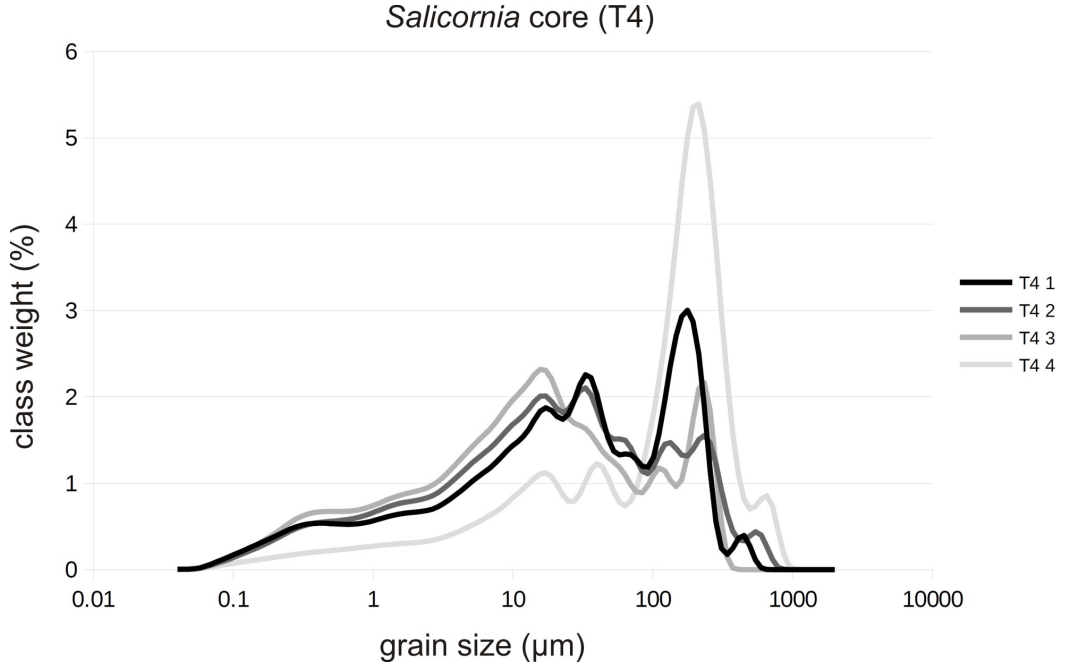


Figure 6.43.: Particle size analysis (PSA) of the *Salicornia* core (T 4) from Gann. Four samples were measured (1-4) which contain a high amount of coarse to fine silt and mud. The exceptions are sample S/4 where the sand fraction is nearly similar or higher as the mud fraction. The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

The particle size analyses of all Gann cores show no correlation between grain size changes and the Foraminiferal assemblages (figure 6.40). Even though the sediment here is better sorted than the one at Tollesbury, the saltmarsh environment was mostly influenced by the sea (figure 6.42 and 6.43).

6.3.4. Loch Riddon saltmarsh samples

From the Loch Riddon saltmarsh, four surface samples as well as three sediment cores were sampled. The core c I is 60 cm deep, the core c II is 70 cm deep and the shortest one c III is 30 cm deep. From the surface samples, Foraminifera and one Ostracoda were found. The sediment cores only contain Foraminifera. For an overview of the sampling locations see chapter 3.2.11.

Loch Riddon surface samples

The four saltmarsh surface samples contain 658 Foraminifera specimens and one Ostracoda. The samples were collected from the high marsh (up), as well as from the marsh plateau, one from a grazed (gr) and one from an ungrazed (ungr) surface. Also, one mudflat (MF) sample was collected. In all four surface samples, 5 Foraminifera species belonging to 5 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Haplophragmoides wilberti* Andersen, 1953 and *Elphidium* spp., see table D.7 about absolute abundance of all species per sample.

The Foraminiferal assemblage in the highest marsh sample (up) is dominated by *H. wilberti* (83%), see figure 6.44. The grazed and ungrazed samples show the same assemblage, consisting of *T. inflata*, *J. macrescens* and *M. fusca*. The first two species are predominating in both samples. The mudflat sample shows a very low Foraminifera abundance, which is dominated by *Elphidium* spp. (68%).

From the Loch Riddon marsh, due to no clearly visible plant zones (because of sheep grazing), the four collected surface samples are representing high marsh (up), marsh plateau (gr and ungr) and mudflat. The Foraminiferal assemblage at the high marsh is dominated by the agglutinated species *H. wilberti*, which was not found at the three previously mentioned sites. The assemblage of the marsh plateau consists of *T. inflata* and *J. macrescens*, with low amounts of *M. fusca* as well, see figure 6.44. In the mudflat, mostly *Elphidium* spp. was found, but in low abundances. This could be, because the sediment of the mudflat consists mostly of coarse sand, which could influence the Foraminifera abundance as well as assemblage, similar to the Gann saltmarsh.

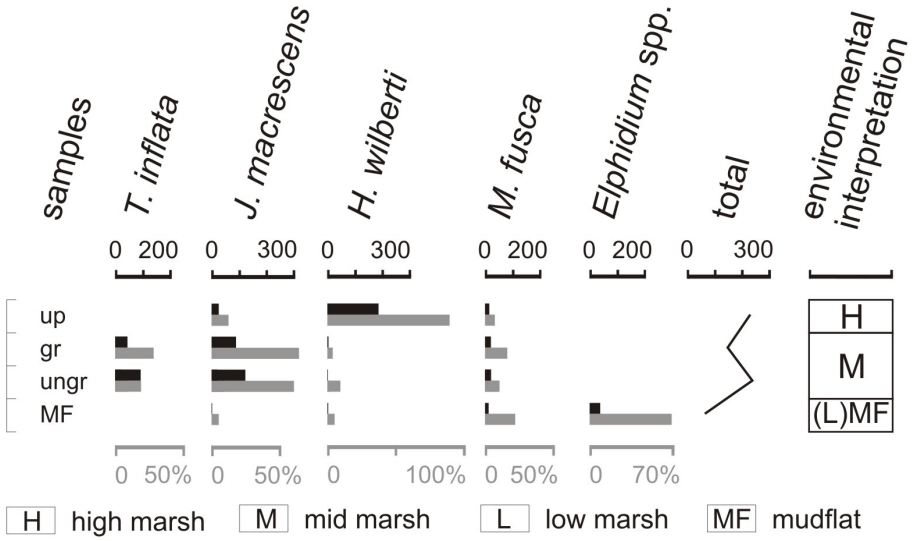


Figure 6.44.: Four saltmarsh surface samples from Loch Riddon. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total).

Only one Ostracoda specimen of *Leptocythere castanea* (Sars, 1866) was identified from the mudflat surface sample (MF), see table E.9.

Loch Riddon sediment cores

The 16 core samples contain 5 719 Foraminifera specimens, no Ostracoda. The core c I was collected from the high marsh area and is divided into six samples (cI 1 to cI 6). The second core (c II) consists of seven samples (cII 1 to cII 7) and was extracted near the marsh edge. The mudflat sediment core c III is split in three samples (cIII 1 to cIII 3). In all 16 core samples, 4 Foraminifera species belonging to 4 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870) and *Haplophragmoides wilberti* Andersen, 1953, see table D.7 about absolute abundance of all species per sample.

In the top sample of the high marsh core (c I), *H. wilberti* (82%) shows its highest abundance in sample cI 1, see figure 6.45. The next three core samples (cI 2 to cI 3) are dominated by *J. macrescens* ranging from 65 to 81%. *M. fusca* increases in abundance with depth (7 to 21%) and until it dominates the next sample cI 5. The lowest core sample (cI 6) contains again more *J. macrescens* (53%) than *M. fusca* (45%).

The second core (c II) shows a clear trend for the species *T. inflata*, *J. macrescens* and *M. fusca*, see figure 6.45. The first two species decrease in abundances with depth, whereas the latter one shows an increase of its abundance. The first three samples (cII 1 to cII 3) are dominated by *J. macrescens* (70 to 86%). And the next lower three samples (cII 4 to cII 6) are dominated by *M. fusca* (53 to 82%). The bottom most sample (cII 7) contains 31% of *J. macrescens* and 69% of *M. fusca*.

The top two mudflat core samples (cIII 1 and cIII 2) show high abundances of *M. fusca* which dominates these samples with 408 and 333 specimens, see figure 6.45. The other three Foraminifera species show a low abundance for both samples. The deepest sample (cIII 3) contains only *J. macrescens* (24%) and *M. fusca* (76%). All three cores contain less than 5% of clay and are mostly dominated by the silt fraction, except the mudflat core (c III). Here the sand fraction is dominating the sediment grain size of all cores with up to 76%.

The two saltmarsh cores c I and c II from the Loch Riddon saltmarsh show a gradual shift from high to low marsh Foraminiferal assemblages with increasing depth (figure 6.45). *H. wilberti* and *T. inflata* are dominating the top samples of the upper core sections of both marsh cores. The species *J. macrescens* decreases with depth in both cores, whereas *M. fusca* shows an increase in abundance with increasing depth, and dominates the mudflat core c III throughout. No calcareous foraminifera were found in the core samples. The Foraminiferal assemblages in both Loch Riddon marsh cores c I and c II show a shift from high to low marsh. This supports Hypothesis 1, where the marsh develops from low to high marsh. This is usually attributed to facilitation succession where the plants accelerated the deposition of sediment raising the elevation. However on a rising coast this change may be affected only by uplift with no additional sedimentation. There was no pioneer zone vegetation and a comparison

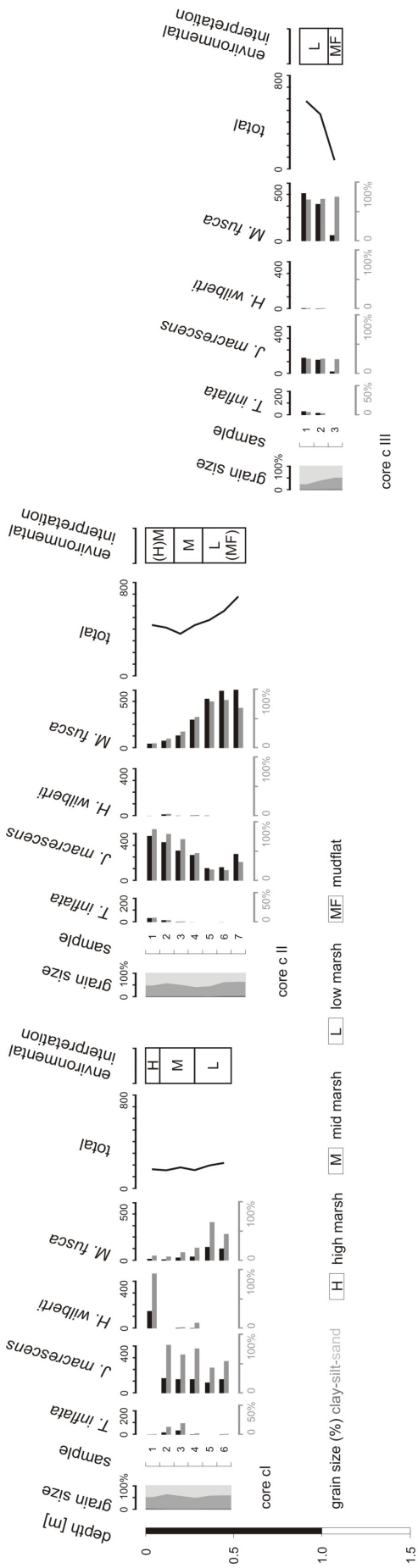


Figure 6.45.: Three saltmarsh sediment cores from Loch Riddon. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total). Also a grain size analysis per core is shown. All cores are correlated to the elevation of the marsh surface.

of this saltmarsh (and others in Scotland) in aerial photographs (Google Earth) with old maps from over a century ago shows no progradation to seaward and part of the marsh shows erosion. If this erosion is due to a changing relative sea-level or the River Ruel flowing in from the hinterland, is not clear. It is possible that the river might have a bigger effect than the relative sea-level in this area of the saltmarsh ecosystem indicated by the results of the PSA. There, all core samples show a well sorted sediment with a grain size of around 70 µm. Also, the grain size changes in the cores does not show correlations with the succession of the Foraminiferal assemblages.

Loch Riddon PSA

A particle size analyses (PSA) was conducted from a 60 cm (c I), a 70 cm (c II) and a 30 cm (c III) deep sediment core from Loch Riddon, see chapter 2.5 about the used methods.

The grain size analysis of all six samples (cI 1 to cI 6) for a 60 cm deep high-mid marsh core (c I) was measured. The sediment core consists of an average of 53% silt and 44% sand, with low clay content, see figure 6.45. The clay content is nearly the same for all six samples, ranging between 3 and 4%. The silt fraction shows two minimum values with 49% at the top sample cI 1 and with 47% at sample cI 4. The sample cI 4 also contains 51% sand. The sand fraction shows other-wise lower values between 37 to 48%. The table G.3 shows the relative clay, silt and sand distribution for all six c I samples. Furthermore, all PSA data from the c I core were plotted as particle diameter in µm (log scale) against the class weight in %, see figure 6.46. All six samples show only one peak for the grain size distribution, which indicates a very good sorting of the grains. The samples show all a similar grain size distribution, with always over 20% of fine sand as well as coarse silt. The mud content of all samples ranges between 49% and 62%, only the clay content of the samples cI 3 and cI 4 show lower values (around 2%) compared with the other samples. For a coloured version of these plots, see figure G.6.

A grain size analyses was conducted on all seven samples (cII 1 to cII 7) from the 70 cm deep mid marsh sediment core (c II). The sediment core consists of an average of 51% sand and 46% silt, with low clay content, see figure 6.45. The clay content is nearly the same for all six samples, ranging between 2 and 4%. The silt fraction shows one minimum at sample cI 4 with 39%, whereas, the samples contain between 43% to 54% silt. The sample cI 4 also contains 59% sand. The sand fraction shows other-wise loser values between 43 to 55%. The table G.3 shows the relative clay, silt and sand distribution for all six c I samples. Also, all PSA data from the c II core were plotted as particle diameter in µm (log scale) against the class weight in %, see figure 6.47. All seven samples show only one peak for the grain size distribution, which indicates a very good sorting of the grains. The samples show all a similar grain size distribution, with always over 26% of fine sand as well as coarse silt. The mud content of all samples ranges between 41% and 57%. The lowest samples cII 6 and cII 7 contain the highest clay content, with over 4%. For a coloured version of these plots, see figure G.7.

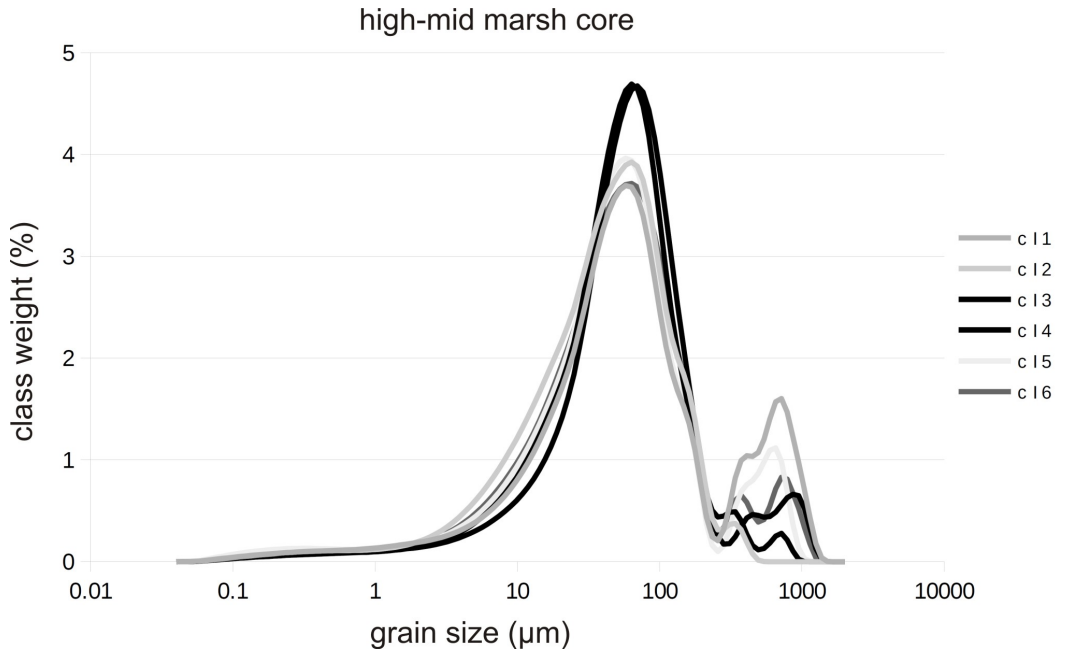


Figure 6.46.: Particle size analysis (PSA) for the high-mid marsh sediment core (c I) from Loch Riddon. 6 samples were measured (cI1 to cI6). The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

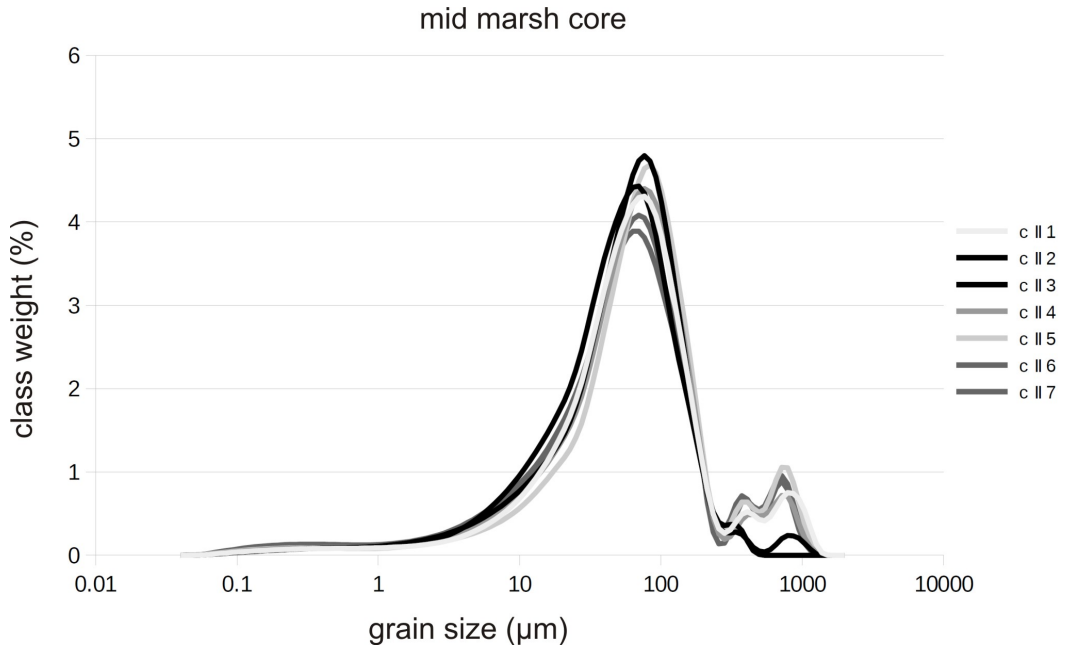


Figure 6.47.: Particle size analysis (PSA) for the mid marsh sediment core (c II) from Loch Riddon. 7 samples were measured (cII1 to cII7). The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

The grain size of all thee samples (cIII 1 to cIII 3) from the 30 cm deep mudflat marsh core (c III) was measured. The sediment core consists of an average of 62% sand and 36% silt, with low clay content, see figure 6.45. The

clay content is nearly the same for all six samples, ranging between 2 and 4%. The silt fraction shows a minimum value of 22% at the top sample cIII 1 and increases to 46% at the lowest samples (cIII 3). The sand fraction shows instead an increasing trend from the bottom (cIII 3) to the top of the core (cIII 1), with 49% to 76%. The table G.3 shows the relative clay, silt and sand distribution for all three c III samples. Furthermore, all PSA data from the c III core were plotted as particle diameter in µm (log scale) against the class weight in %, see figure 6.48. All six samples show only one peak for the grain size distribution, which indicates a very good sorting of the grains. The samples all show all a similar grain size distribution, with always over 30% of fine sand. The clay content increase with 2% to 4% with depth. For a coloured version of these plots, see figure G.8.

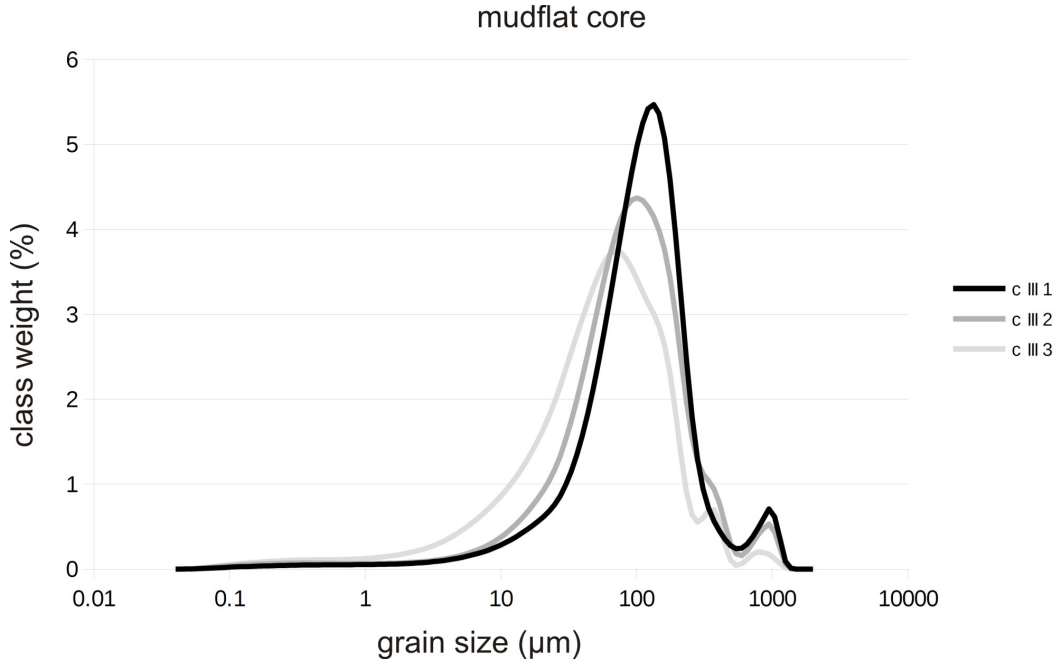


Figure 6.48.: Particle size analysis (PSA) for the mudflat sediment core (c III) from Loch Riddon. 3 samples were measured (cIII1 to cIII3). The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

The grain size analyses for all Loch Riddon cores does not show any correlation between the grain size changes and the Foraminiferal assemblages (figure 6.45). However, the saltmarsh environment was most likely be influenced by the River Ruel than the sea due to a very well sorted sediment (figure 6.46, 6.47 and 6.48).

6.3.5. Kyleakin saltmarsh samples

From the saltmarsh near Kyleakin, four surface samples as well as two sediment cores, one with 50 cm and one with 60 cm length, were samples. From the surface samples, Foraminifera and Ostracoda were found. The sediment cores only contain Foraminifera. For an overview of the sampling locations see chapter 3.2.12.

Kyleakin surface samples

The four saltmarsh surface samples contain 1 188 Foraminifera and 586 Ostracoda specimens. The samples were collected from the high (cI sur) and low marsh (LM 2), as well as one from a salt pan (SPW) and mudflat (MF). In all four surface samples, 4 Foraminifera species belonging to 4 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870) and *Haplophragmoides wilberti* Andersen, 1953, see table D.8 about absolute abundance of all species per sample.

In the highest surface sample (cI sur), collected near the high marsh sediment core (c I), all four above mentioned Foraminifera species were found, see figure 6.49. *M. fusca* dominates the Foraminiferal assemblage with 56%, whereas the other three species show a relative abundance between 10 to 19%. This surface samples is also the only one of all four that contains *H. wilberti*. From the low marsh sample (LM 2), the species *T. inflata* (60%) and *M. fusca* (35%) were identified. The salt pan sample (SPW) also contains the same assemblage as LM 2, where 57% of *T. inflata* and 43% of *M. fusca* were found. The mudflat surface sample (MF) is dominated by *M. fusca* (97%), only four specimens of *T. inflata* were found.

Only agglutinated species have been found here, no calcareous forms, see figure 6.49. The high marsh Foraminiferal assemblage is the most diverse sample containing four different species, which declines with decreasing elevation, so that in the mudflat only *M. fusca* is present. Again, *H. wilberti* appears in the high marsh together with *T. inflata* and *J. macrescens*. All four samples are dominated by *M. fusca*.

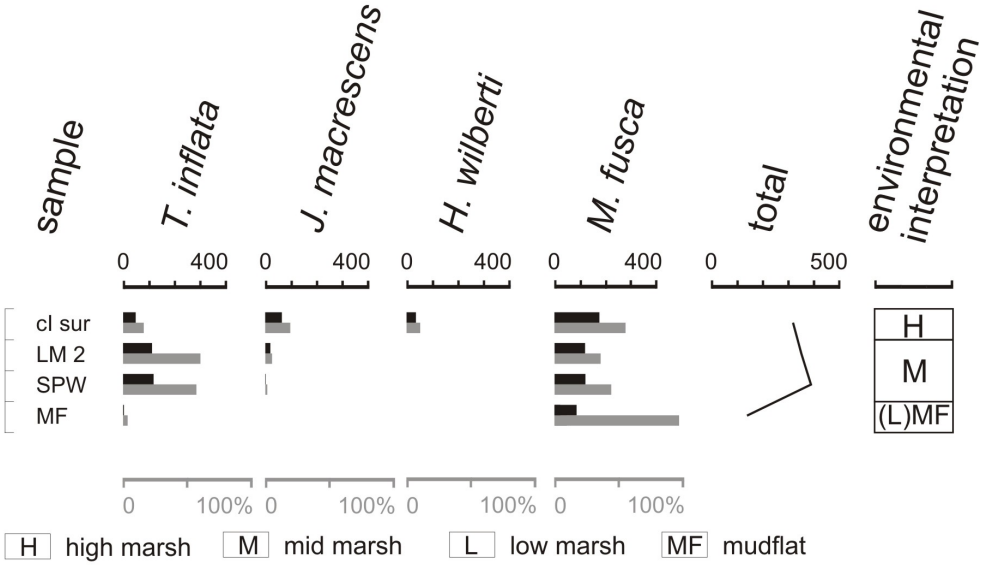


Figure 6.49.: Four saltmarsh surface samples from Kyleakin. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance amount of all picked specimens per sample (total).

The only Ostracoda species that was identified in the surface samples was *Cyprideis torosa* (Jones, 1850), see table D.8. It shows a living population in two (SPW and MF) of the four surface samples.

Kyleakin sediment cores

The 11 core samples contain 4 123 Foraminifera specimens, no Ostracoda. The core c I was collected from the high marsh area and is divided into five samples (cI 1 to cI 5). The second core (c II) consists of six samples (cII 1 to cII 6) and was extracted from a high-mid marsh zone. In all 11 core samples, 4 Foraminifera species belonging to 4 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870) and *Haplophragmoides wilberti* Andersen, 1953, see table D.8 about absolute abundance of all species per sample.

The top most samples (cI 1 and cI 2) of the first core (c I), contain the same Foraminiferal assemblage which consists of *T. inflata* (19 and 35%), *J. macrescens* (26 and 19%), *M. fusca* (47 and 45%) and *H. wilberti* (7 and 1%), see figure 6.50. The remaining three core samples (cI 3 to cI 5) contain only *T. inflata*, *J. macrescens* and *M. fusca*. *T. inflata* is the most dominant species in all samples with a maximum of 69%. The other two species show low abundances, ranging from 9 to 30% for *J. macrescens*, and 16 to 31% for *M. fusca*.

All samples of the mid marsh core (c II) contain only thee Foraminifera species: *T. inflata*, *J. macrescens* and*M. fusca*, see figure 6.50. The first two samples (cII 1 and cII 2) are dominated by *T. inflata* with 93% and 46%. Then, in sample cII 3, *M. fusca* shows the highest abundance of the assemblage which continuous for the next two samples as well (cII 4 and cII 5). The lowest sample contains 38% of *T. inflata*, 56% of *M. fusca* and 6% of *J. macrescens*.

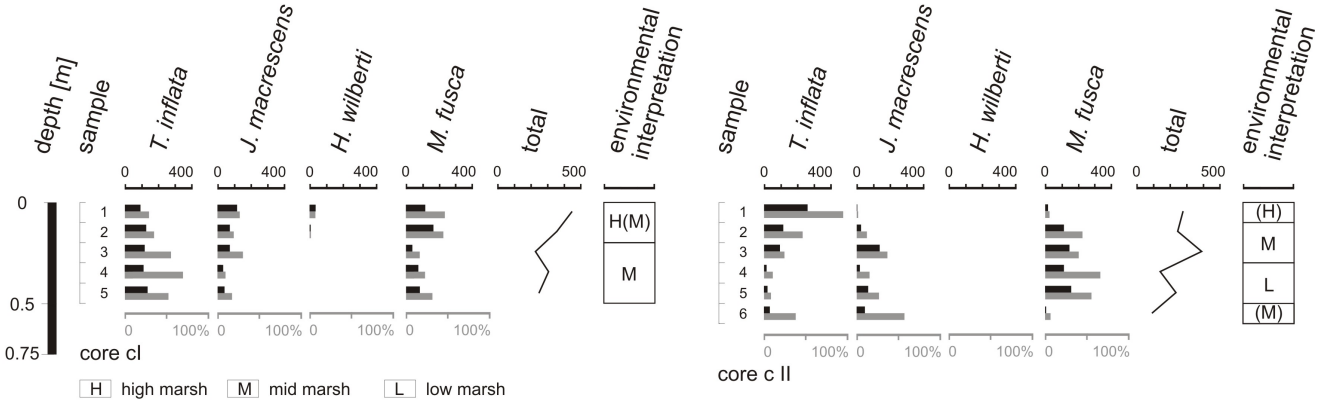


Figure 6.50.: Two saltmarsh sediment cores from Kyleakin. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total). All cores are correlated to the elevation of the marsh surface.

All core samples contain agglutinated Foraminifera exclusively, see figure 6.50. The top sample of core c I contains *H. wilberti*, indicating high marsh. However, the mid marsh species *M. fusca* also occurs in the top two

samples with higher abundances than in the lower three core samples. The abundance of *T. inflata* increases with depth, but so does *M. fusca*. This coexistence of *T. inflata* and *M. fusca* can also be seen in the surface samples of this saltmarsh. Therefore, the other species have to be considered as well. *J. macrescens* shows an increasing trend from bottom to top of the core and in combination with the presence of *H. wilberti* in the top two samples (figure 6.50), a possible marsh succession from mid to high marsh could be interpreted which supports Hypothesis 1.

The core c II shows (high-)mid marsh condition at the top, with *J. macrescens* dominating the Foraminiferal assemblage, but it declines with depth. A reversed distribution pattern can be seen for *M. fusca*, indicating low marsh conditions with its highest abundance in the middle of the core. This could indicate a marsh development from a mid marsh (bottom most sample) to a low marsh (middle core) and into a mid marsh again at the two top most samples until present. The overall trend of the Foraminiferal assemblage in this core (figure 6.50), show a development of the saltmarsh from low to mid, supporting Hypothesis 1.

Shennan & Horton (2002) presents relative sea-level curves for the UK coast, including the Isle of Skye, which showed a relative sea-level drop for the last approximately 6 000 years. However, Teasdale et al. (2011) presents results indicating that the relative sea-level rise out-competes the land uplift in northern Scotland, leading to increased sedimentation rates over the last 100 years. And since the age of the sediment cores from Kyleakin is unknown, it cannot be predicted how the changing relative sea-level influenced the saltmarsh development, if any occurred.

6.3.6. Loch Ainort saltmarsh samples

One surface sample as well as 11 sediment core samples, from a 40 cm (c I) and a 70 cm deep (c II) core, were extracted from the Loch Ainort saltmarsh. All surface and core samples contain only Foraminifera, no Ostracoda were found. A map of the saltmarsh with the sampling spots can be found in chapter 3.2.13.

Loch Ainort surface samples

One surface sample (sur) was collected from the marsh plateau, and contains 209 Foraminifera specimens. 2 species were identified, which belong to 2 genera: *Jadammina macrescens* (Brady, 1870) and *Miliammina fusca* (Brady, 1870), see table D.9 about absolute abundance of all species per sample. The sample contains more *J. macrescens* (72%) than *M. fusca* (28).

Loch Ainort sediment cores

The 40 cm deep sediment core c I was extracted from the marsh plateau and divided into four samples (cI 1 to cI 2). Where heather was growing at the higher marsh area, the 70 cm deep sediment core c II was taken, which consists

of seven core samples (cII 1 to cII 7). In total, 408 Foraminifera specimens from 3 species belonging to 3 genera were picked: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870) and *Miliammina fusca* (Brady, 1870), see table D.9 about absolute abundance of all species per sample.

From the first sediment core (c I), all samples contain only *J. macrescens*, see figure 6.51. The highest abundance of this species is in the top sample with 144 specimens. The lower samples contain between 10 to 18 tests. However, the identified *J. macrescens* could also be mistaken with *H. wilberti*, because their tests were too small and deformed to see the aperture (for identification) clearly.

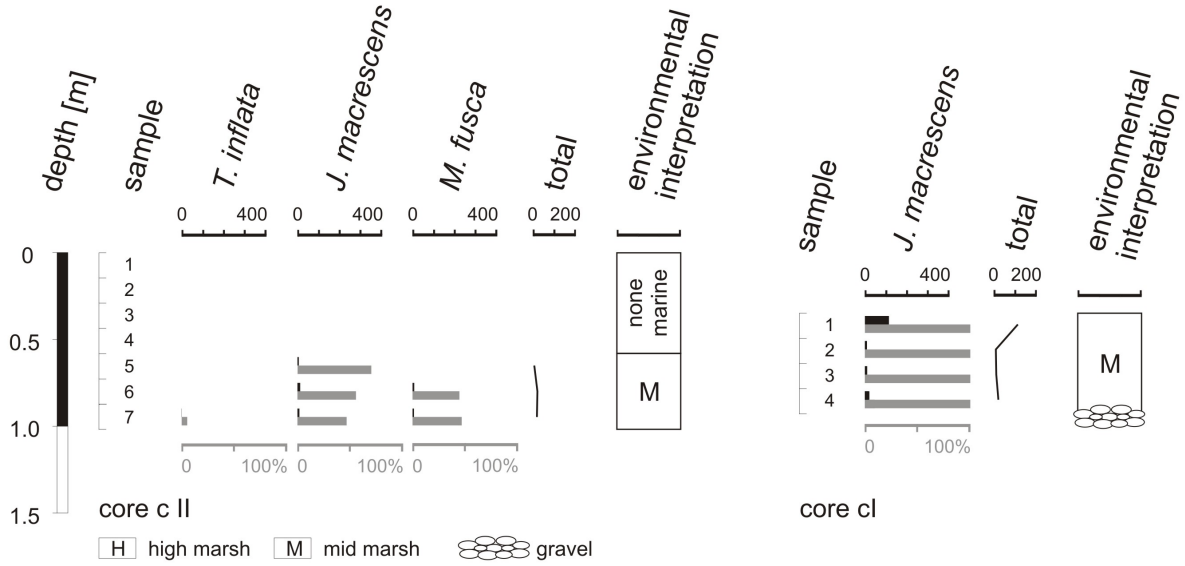


Figure 6.51.: Two sediment core from the Loch Ainort saltmarsh. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total). Both cores are correlated to the elevation of the marsh surface.

The heather sediment core (c II) contains Foraminifera tests, but only in the lowest three samples (cII 5 to cII 7), see figure 6.51. The top four samples (cII 1 to cII 4) contain no microfossils. Five specimens of *J. macrescens* (100%) were found in sample cII 5. From the sample cII 6, only *J. macrescens* (55%) and *M. fusca* (45%) were identified. The lowest sample (cII 7) contains all three species, where *J. macrescens* (47%) and *M. fusca* (47%) are the most abundant ones.

Both sediment cores contain agglutinated Foraminifera only. All samples from c I are dominated by the species *J. macrescens*, which indicates mid marsh throughout. The second core contains Foraminifera only in the lowest three samples which were also dominated by *J. macrescens* throughout. This means that mid marsh was found for both sediment cores, to support Hypothesis 2.

However, due to the absence of Foraminifera species in the top 60 cm of core c II, it can be assumed that the heather was growing on top during a relative sea-level drop (or stagnation), because the surface was not inundated.

As mentioned earlier, this could have occurred between the last 6 000 years and present, where a sea-level drop is known from the Isle of Skye (Shennan & Horton, 2002).

For both saltmarsh cores, the elevation of their sampling surface is known (figure 6.13), therefore the samples of both cores can be correlated to each other, which is shown in figure 6.13. Here, the top saltmarsh sample (7) of the heather core (c II) represents a paleo saltmarsh surface, which is lower than the present marsh surface, indicated by the top sample of core I (cI 1). This means that after the relative sea-level dropped, at one time it was rising again to the present marsh surface (cI 1). Therefore, the saltmarsh sediment in core I could indicate this rising sea-level (Hypothesis 2).

6.3.7. Loch Sligachan saltmarsh samples

No surface samples were analysed for the Loch Sligachan study site due to mid tide when sampling. Only a 50 cm deep sediment core (c I) was collected from the marsh rim, close to the road. The core samples contain Foraminifera only, no Ostracoda were found. A map of the area with the sampling location can be found in chapter 3.2.13.

Loch Sligachan sediment core

The 50 cm deep sediment core c I was extracted from the marsh rim and divided into 10 cm long samples each, leading to 5 core samples (cI 1 to cI 5). In total, 843 Foraminifera specimens with 2 species belonging to 2 genera were picked: *Jadammina macrescens* (Brady, 1870) and *Miliammina fusca* (Brady, 1870), see table D.10 about absolute abundance of all species per sample.

All core samples contain both Foraminifera species, see figure 6.52. The species *J. macrescens* in the top two samples (cI 1 and cI 2) is dominating the assemblage with 59% and 66%. The sample cI 3 contains more *M. fusca* (68%) than *J. macrescens* (32%). The sample cI 4 is also dominated by *M. fusca* (55%). The lowest samples (cI 5) contains again more *J. macrescens* (84%) than *M. fusca* (16%).

The only core from Loch Sligachan contains two agglutinated species: *M. fusca* and *J. macrescens*. The lowest sample is dominated by the latter species which shows a decrease in abundance up to 30 cm depth, where it then increases again. The reverse pattern can be seen for *M. fusca*, showing its highest abundance at 30 cm depth. No surface samples were collected from this site. Therefore, it is assumed that *J. macrescens* is indicating high-mid marsh and *M. fusca* low marsh, due to a similar Foraminiferal assemblage found at the nearby Loch Ainort saltmarsh. The Foraminifera in core c I indicate a trend from bottom to top, ranging from high-mid to low and to high-mid again, which seems to support Hypothesis 2.

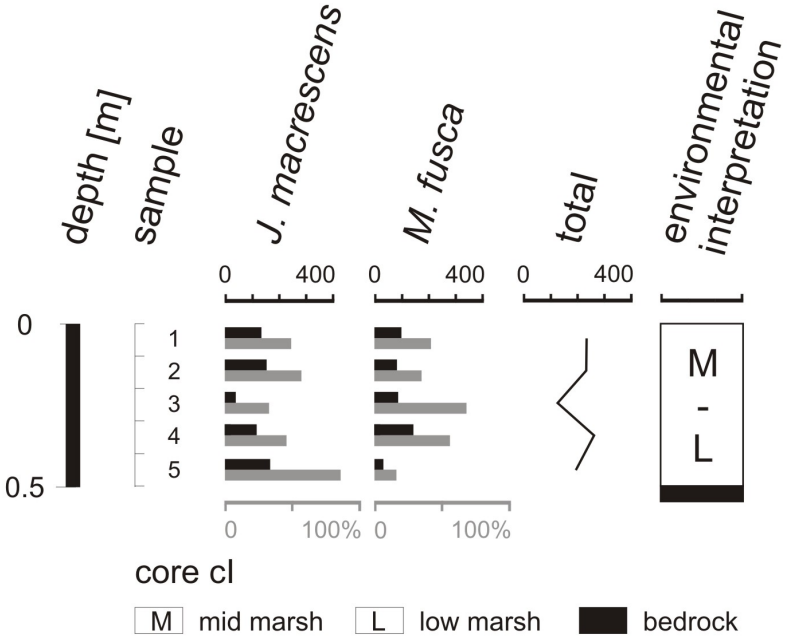


Figure 6.52.: Loch Sligachan saltmarsh sediment core. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total).

6.3.8. Holkham and Stiffkey saltmarsh samples

From the north Norfolk coast saltmarsh, three surface samples (HM 1, MM 1, LM 1) from Stiffkey were collected, as well as a 9 m long sediment core (NNC 17) from Holkham re-sampled at the BGS. In total, 27 core samples (R1 1 to R9 3) were extracted, with three samples per metre, but only twelve were analysed for microfossils. Furthermore, a PSA of all 27 core samples was conducted. For an overview of the exact sampling location of the core, see chapter 3.2.15.

Stiffkey surface samples

The three saltmarsh surface samples contain Foraminifera with 525 specimens. No Ostracoda were found. Samples were collected from the high (HM 1), mid (MM 1) and low marsh (LM 1). In all three surface samples, 5 Foraminifera species belonging to 5 genera were identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Miliammina fusca* (Brady, 1870), *Quinqueloculina* spp. and *Elphidium* spp., see table D.11 for absolute abundance of all species per sample.

The high marsh sample (HM 1) contains 233 Foraminifera specimens, which are dominated by *T. inflata* with 78%, see figure 6.53. *J. macrescens* (14%), *M. fusca* (6%) and *Quinqueloculina* spp. (3%). The mid marsh sample (MM 1) contains 290 tests, with the highest abundance of 82% *T. inflata*. Low abundances of the species

J. macrescens (6%), *M. fusca* (8%), *Quinqueloculina* spp. (6%) and *Elphidium* spp. (3%) were also found. The low marsh sample (LM 1) contains only one species of *J. macrescens* and *Quinqueloculina* spp..

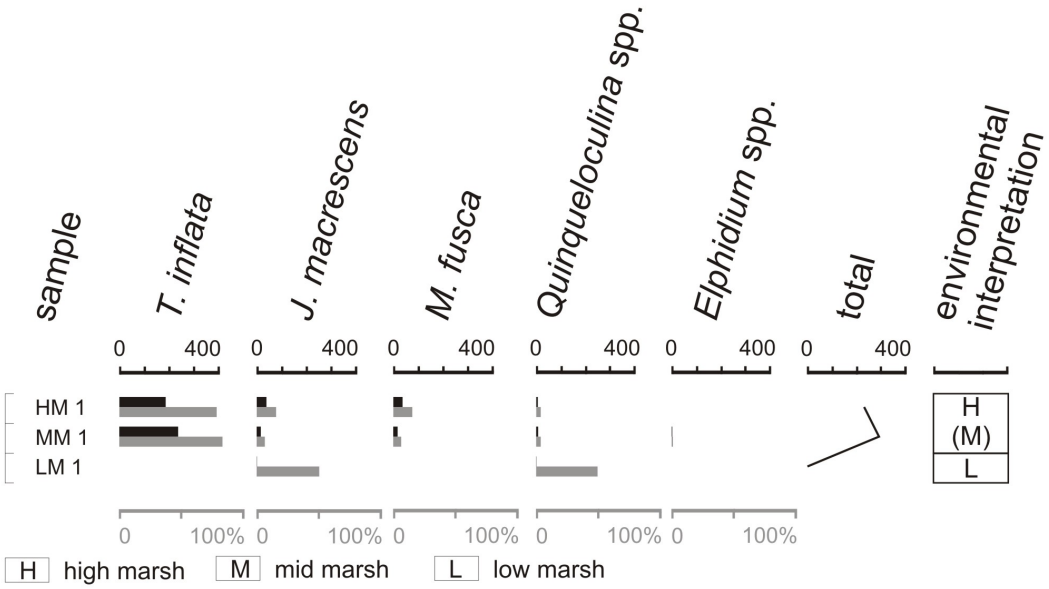


Figure 6.53.: Stiffkey saltmarsh surface samples, showing per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species, including the absolute abundance of all picked specimens (total).

From the three surface samples from Stiffkey, the high and mid marsh ones are dominated by *T. inflata*, see figure 6.53. Lower abundances of *J. macrescens* and *M. fusca* were also found. The low marsh sample contains only two calcareous specimens.

Holkham sediment core

As described in chapter 3.2.15, the 9 m deep sediment core (NNC 17) was taken as part of a NERC funded project in 1997. Therefore, the sediment core was re-sampled at the BGS where it is stored. From the twelve analysed core samples (R 1/1 to R 9/3), a total of 1 356 Foraminifera and 4 Ostracoda specimens were found. However, due to the dried out sediment, as well as the preparation of the samples, influenced the preservation of the microfossils. This led to with gypsum crystals overgrown shells, especially the Ostracoda valves. Also, the tests were often broken and in bad conditions (especially the agglutinated forms). Therefore, for each sample the whole sediment material was sorted through, see table B.12.

Only Ostracoda valves were found in the four metre (R 4/1) and seven metre (R 7/1) samples. Also, broken pieces of valves were identified in the six metre (R 6/1) sample as well. All four valves could be identified as *L. porcellanea*, see table E.11.

Foraminifera tests were found in ten of twelve core samples, where R 1/1 and R 9/1 contain none. 6 Foraminifera species belonging to 6 genera could be identified: *Trochammina inflata* (Montagu, 1808), *Jadammina macrescens* (Brady, 1870), *Ammonia* spp., *Elphidium* spp., *Haynesina germanica* (Ehrenberg, 1840) and *Globigerina* sp., see table D.12 about the absolute abundance of Foraminifera species per sample.

The figure 6.54 shows the absolute (black bars) and relative abundance (grey bars) per sample for all analysed core samples. The top metre with the three samples (R 1/1, R 1/2, R 1/3) only contains the agglutinated form *J. macrences*, with 75 and 4 specimens in sample R 1/1 and R 1/3. No Foraminifera were found in sample R 1/2. The samples R 2/1 and R 3/1 contain 7 and 10 tests, which are dominated by the species *Ammonia* spp. (57 and 40%). 263 Foraminifera specimens were found in sample R 4/1, with an assemblage consisting of *H. germanica* (53%), *Ammonia* spp. (25%), *Elphidium* spp. (11%) and *T. inflata* (9%). The following core samples (R 5/1 and R 6/1), contain 53 and 87 tests per sample, and show a similar Foraminiferal assemblage compared to the latter sample which consists of: *J. macrescens* (47 and 46%), *H. germanica* (42 and 41%), *Ammonia* spp. (9 and 10%) and *Elphidium* spp. (2 and 1%). The highest absolute abundance of specimens from all core samples, with 525 tests was picked from sample R 7/1. Here, the Foraminiferal assemblage was similar to the one in the previous samples, but *H. germanica* is the dominating species with 83%. The same assemblage was also found in sample R 8/1, which shows an absolute abundance of 314 specimens. From the last metre of the core, the sample R 9/1 contains 24 Foraminifera tests, of which 23 specimens belong to *T. inflata* and *J. macrescens*. The lowest sample, R 9/3 contains no microfossils, and only consists of peat.

The silt dominates the sediment grain size, however, the sand fraction shows increased values at 1.5 m, 3.5 m and 9.5 m depth with up to 40%. The clay content always stays below 25%. The marsh developed on top of a peat layer.

The NNC 17 from Holkham was re-sampled, data about the Foraminiferal assemblages can be found in Horton & Edwards (2005). The bottom most sample contains high amounts of the high marsh Foraminifera *T. inflata*, as well as the top two core samples (figure 6.54). The succession of the Foraminiferal assemblages indicate a high marsh at the bottom of the core which changes into mid marsh until sample R6/1. Then low marsh Foraminiferal assemblages are found in sample R5/1 and R4/1, with hardly to no agglutinated tests. Sample R3/1 and R2/1 indicate mid marsh conditions again due to the low abundance of calcareous specimens. And the top metre of the core indicates high marsh again. The figure 6.55 shows that at 9 m a layer of peat exists, this would indicate that the marsh started as a high marsh, then changed into a mid and low marsh. This development of marsh zones (high to low) support Hypothesis 2.

Only the change from high to low marsh, starting at the bottom most sample of the core can also be seen in figure 6.55. Here, the calcareous Foraminifera dominates all samples, except between 6 and 7 m depth, where *J.*

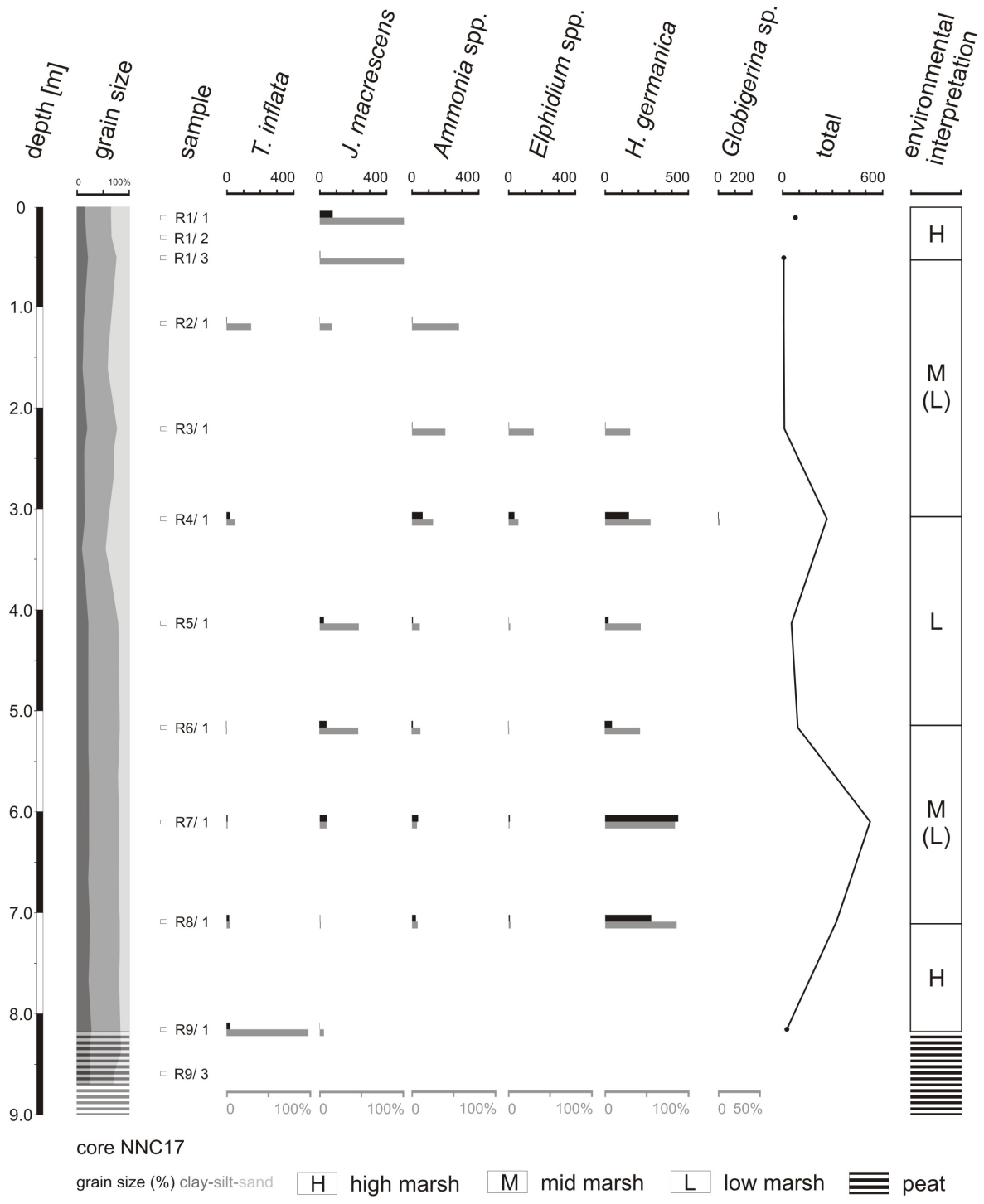


Figure 6.54.: Holkham NNC 17 9 m deep sediment core. Per sample the absolute (black bars) and relative (grey bars) abundance of Foraminifera species are shown, including the absolute abundance of all picked specimens per sample (total). Also a grain size analysis is shown.

macrescens shows its highest abundance. The above described trend in appearances of *H. germanica* can be seen again, a slight decrease towards the top. However, no *T. inflata* were recorded from these samples. The overall trend shows that the high marsh started above the layer of peat and changed to low marsh between 6 and 1 m depth (O.D.).

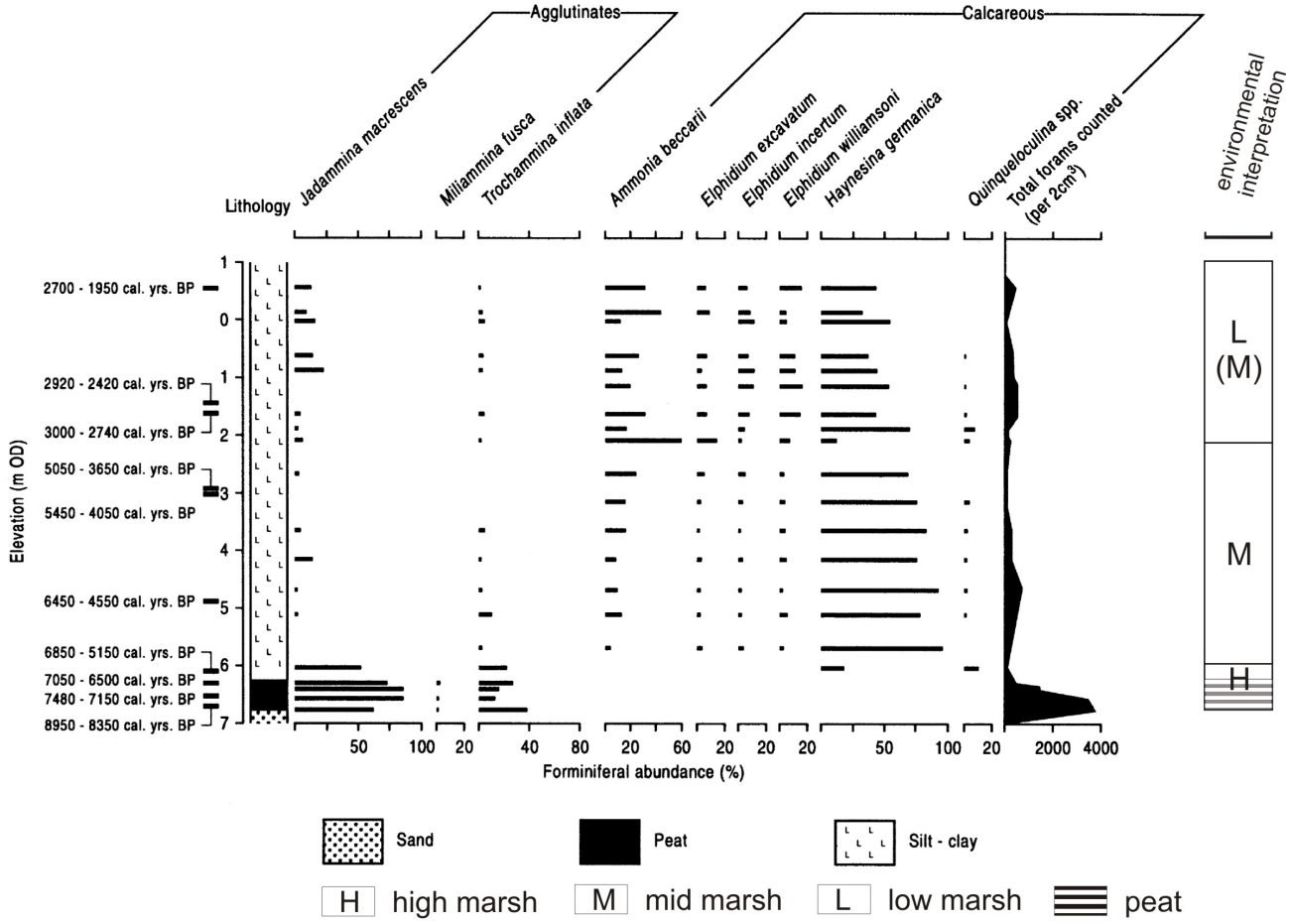


Figure 6.55.: Holkham NNC 17 7 m deep sediment core (scale in O.D.). Per sample the relative abundance (black bars) of the most common Foraminifera. Also, the sediment was dates throughout the core and the sediment types are indicated. Figure copied from Horton & Edwards (2005).

Holkham PSA

A particle size analysis (PSA) was conducted for all 27 samples (R 1/1 to R 9/3) from the 9 m long (NNC 17) sediment core, see chapter 2.5 about methods. The sediment core consists of an average of 54% silt, with lower contents of sand (27%) and clay (20%), see figure 6.54. The clay content shows an increasing trend from the top to the bottom of the core, ranging from 16% (R 1/1) up to 25% (R 9/3). The silt content in all samples shows similar values, between 43% to 61%. At sample R 2/3 the sand fraction shows a peak (41%) as well as at sample R 4/2 with 46%. Sample R 9 /2 contained the lowest amount of sand The table G.4 shows the relative clay, silt

and sand distribution for all 25 TCE samples. Also, all PSA data from the NNC 17 core were plotted as particle diameter in µm (log scale) against the class weight in %, see figure 6.56. The 28 graphs show that the sediment of the core consists mainly of mud (clay and coarse silt). The core shows higher amounts of mud (clay with over 20%) in the lower samples (R 5/1 to R 9/3). The last two samples (R 9/2 and R 9/3) contain the highest fine silt amount of all samples, with a maximum of 14%. The samples R 5/1 to R 9/1 show higher amounts of medium and coarse silt than the samples above (over 22%). At sample R 4/3 upwards until the top of the core, the fine sand fraction increases from 10% up to a maximum of 29% in sample R 2/3. For a coloured version of these plots, see figure G.9.

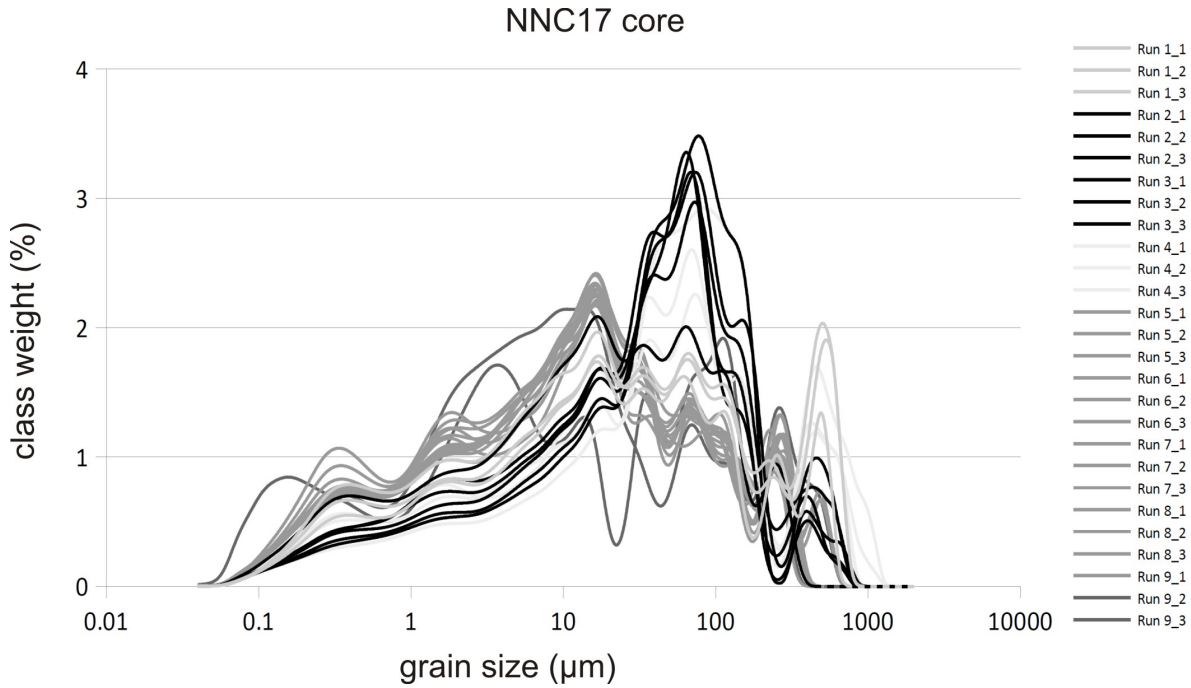


Figure 6.56.: Particle size analysis (PSA) for the sediment core (NNC 17) from Holkham, showing all 27 samples. The x-axis represents the grain size in µm (log scale) whereas the y-axis stands for the class weight % per sample.

No clear correlation between the grain size succession and Foraminiferal assemblages can be seen (figure 6.54). The poorly sorted sediment reveals a saltmarsh environment that was dominated by the sea (figure 6.56).

6.3.9. Foraminifera surface samples

Comparing the Foraminiferal assemblages from the surface samples at all sites, the species diversity shows a decrease with increasing geographical latitude. This could be related to the decrease in plant species (and zones) from south to north observed on the marsh surface (chapter 3.2), which leads to a single marsh zone at Loch Ainort and Loch Sligachan. It could also be argued that this trend is due to the changing sediment (Gupta, 1999), as the mud and silt rich sediments in the south change to a sandier environment further north, because of the underlying

geology (British Geological Survey, 1832). Only the "*Ammonia* group and *Haynesina germanica* are common in sediments with more than 80% mud/silt [content]" (Murray, 2006). However, for the remaining species this is most likely not the case, due to an observed muddier sediment at Kyleakin, which still contains a similar Foraminiferal assemblage compared to the ones found at the other northern study sites (LR and LA). The possibility that salinity influences the Foraminifera distribution can be disregarded as well, because the Foraminifera in UK saltmarshes show a stronger correlation to elevation (Horton, 1999; Horton & Edwards, 2005; Horton & Edwards, 2006b). This can be seen from the elevation measurements, where the marsh surfaces are located above the MHWNT levels, as seen in chapter 6.1.3. Therefore, the plant species show a distinctive vegetational zonation (e.g. at Tollesbury, chapter 6.1.2) according to the different tides (Waisel, 1972; Chapman, 1974; Roman, 2001; Bockelmann et al., 2002), which restrict the inhabiting fauna to these zones (Long & Mason, 1983; Funnell & Pearson, 1989; Brew et al., 1992; Gupta, 1999). Therefore, as stated above, the reason for the decreasing trend of the identified Foraminiferal assemblages is probably correlated with the decreasing number of marsh zones. This means that the Foraminifera diversity, and assemblages, correlate with the marsh zones, which can be used to distinguish marsh zones within saltmarsh sediment cores. This correlation, between marsh zones and Foraminiferal assemblages, is already utilised in sea-level studies, where saltmarsh sediment cores are analysed with the help of Foraminifera species to reconstruct paleo-sea-levels (Scott & Medioli, 1978; Horton, 1997; Gehrels, 2000; Edwards & Horton, 2000; Haslett et al., 2001; Gehrels & Newman, 2004; Horton & Murray, 2006; Horton & Cluver, 2008; Callard et al., 2011; Mills, 2011; Kemp et al., 2012; Barlow et al., 2014). Nevertheless, the surface data on Foraminiferal assemblages from the study sites had to be tested, before they could be applied to identify saltmarsh zones from sediment cores. The seasonal study also revealed that the Foraminifera species and their assemblages correlate with saltmarsh zones (chapter 6.2.1).

Furthermore, the species diversity also shows a change regarding the Foraminifera test composition, see table 6.6. Where agglutinated and calcareous forms coexist at the southern sampling sites (T, TTI, G, SK), the Foraminiferal assemblages from the northern study sites (LR, KY, LA) contain almost exclusively agglutinated forms, except the mudflat sample from Loch Riddon. A reason for this change could be that agglutinated species are better adapted to higher environmental stress, which increases within a marsh from the low to high zones (Long & Mason, 1983). Therefore, agglutinated species normally dominate the high to mid marsh zones (Murray, 2013). This means that with increasing geographical latitude, the environmental stress factors (e.g. colder climate) also increase, but agglutinated Foraminifera still seem to be able to adapt to the harsher conditions. The "brackish marsh foraminifera at high latitudes must experience severe freezing during the winter (down to at least -10°C)" (Murray, 2006). And for example, the agglutinated species *H. wilberti* occurs first in the surface samples at Loch Riddon and continues to occur at both northern study sites (KY, LA?) as well. In contrast, the calcareous forms, with their restricted distribution to low and mid marsh, disappear from this environment. The absence of

calcareous species opens up new niches for agglutinated forms which show a broader marsh zone distribution, as it is observed from other species (Frenzel, 2009). The best example for this is *M. fusca*, normally occurring in low abundances in the high-mid marsh zones (Murray, 2013) (figure 6.26), is then found most abundant at low marsh, e.g. at Kyleakin saltmarsh (figure 6.49). This agglutinated species was also found in higher abundances from other northern locations around the Isle of Skye (Horton, 1997). Therefore, when using the Foraminiferal assemblages from the surface samples to compare with those in core samples, it is imperative to know if, for example, *M. fusca* indicates high-mid or low marsh conditions. Thus, the predominant species from each marsh zone per saltmarsh site was identified, in order to use them to distinguish between marsh zones in sediment cores. "Each salt marsh has its own characteristics. Regional factors such as climate play an important role [...]. Thus each marsh has its own foraminiferal fingerprint showing the opportunistic behaviour of the salt marsh agglutinants. A surface study is an indispensable first step in assessing the value of foraminifera as paleo-ecological indicators." (de Rijk & Troelstra, 1997). The table 6.6 shows the most abundant species per study site, which also were used as marsh zone indicators for the respective sediment cores.

Table 6.6.: A distribution of the most common Foraminifera species for all surface samples from the study sites Tollesbury (T), Two Tree Island (TTI), Gann (G), Loch Riddon (LR), Kyleakin (KY), Loch Ainort (LA) and Stiffkey (SK). Also shown is the species distribution per marsh zone (H=high, M=mid, L=low).

species	**SK**	**T**	**TTI**	**G**	**LR**	**KY**	**LA**
H. wilberti					H	H	(H)
T. inflata	H	H	H	H	H	H	
J. macrescens	M	H	H	M	M	M	H - M
M. fusca	M	M	M	M	L	L	L
Quinqueloculina spp.	L	M	M	L			
Ammonia spp.		L	L	L			
Elphidium spp.	L	L	L	L	L		
H. germanica		L	L	L			

Regardless of the difference between the higher Foraminifera species diversity in the southern study sites (Holkham, Tollesbury, Two Tree Island, Gann) compared to the northern sites, each marsh zone could be identified with a Foraminiferal assemblages per marsh zone (high, mid, low). For example, the surface sample from Tollesbury extracted from the high marsh (*Elytigia*) contained predominantly the agglutinated species *T. inflata*

and *J. macrescens*, see figure 6.26. When this assemblage is then compared to the sediment core samples from the same saltmarsh, the high marsh conditions could be identified within the core, see figure 6.28. This method was also used for identifying the mid and low marsh as well as mudflat, if possible, which helped to reconstruct the marsh development of each core. Therefore, for each study site, the surface samples with their unique Foraminiferal assemblage had to be considered before using it to identifying the marsh zones for each core.

6.3.10. Ostracoda surface samples

Besides using Foraminifera for marsh zone reconstruction from saltmarsh sediment cores, it was attempted to identify any specific Ostracoda assemblages or species per marsh zone. Ostracoda were found abundant at the Tollesbury and Gann saltmarsh as well as two other sites Two Tree Island and Kyleakin.

From all surface samples, only *L. malcomsoni* and *Terrestricythere* sp. at Tollesbury could be related to a specific marsh zone (due to re-sampling), which was mentioned above. All other Ostracoda species often show no clear correlation to a specific marsh zone beyond their own study site. On the one hand, this is because even though high abundances of one species appear at one saltmarsh site, at the next it is hardly present or even absent. For example, *L. elliptica* only occurs in higher numbers at Gann (figure 6.39), nowhere else can it be found with the same abundance (figure 6.34) or at the same marsh zone. On the other hand, re-sampling the same saltmarsh zone did not always lead to the same abundance of Ostracoda species, see chapter 6.4. For example the species *L. porcellanea* from the sampling campaign in 2013 from the low marsh area (R 1, R 2) contained a very low abundance, but from the same marsh zone (R 3, R 4) which was re-sampled the year after, higher abundances of this species were found, see chapter 6.4. Another problem of Ostracoda is that their distribution within a saltmarsh often depended on other factors than elevation, e.g grain size (Barker, 1983). Or, as it was found, that a species occur in high abundances from one marsh zone at one sampling spot, but at the next sampling spot, from the same marsh zone, very low abundances or no species would be found. This was the case for the species *X. labiata*, where it appeared in the one low marsh sample R 1 with nearly 100 specimens, it did not occur at all in the other low marsh sample R 2 also from the same marsh zone. This patchy distribution was also found for other Ostracoda species from the Isle of Wight. Ostracoda could be used as saltmarsh zone indicators, e.g. for sea-level reconstructions (Boomer, 1998; Frenzel & Boomer, 2005; Cronin et al., 2010; Scott et al., 2011). However, the results here indicate that besides the already mentioned two species, the distribution of the other Ostracoda species were not restricted to distinct marsh zones. Furthermore, even if the results would indicate otherwise, only the saltmarsh sediment cores from Gann and Two Tree Island contained Ostracoda (with low abundances per species only), most of the time none were found in core samples.

6.3.11. Foraminifera core samples

After the Foraminiferal assemblages for the high, mid and low marsh zones were identified for each study site (chapter 6.3.9), the assemblages of each sediment core sample was analysed to see whether the marsh zone succession would support Hypothesis 1 or Hypothesis 2, see figure 6.57. It is to mention here that only Foraminiferal assemblages were used to reconstruct the marsh development due to the absence of Ostracoda in most saltmarsh cores. Only in the Two Tree Island sediment core (TCP) a high abundance of Ostracoda species were found, which was additionally used to reconstruct the environmental development before the saltmarsh started forming (chapter 6.3.2).

From the main study site at Tollesbury (T), two sediment cores were analysed and with their succession of throughout high(-mid) marsh for both cores, Hypothesis 2 is supported (figure 6.57). The same results were found for three more saltmarsh cores from this site, collected during a master project (Janie, 2011). The Two Tree Island (TTI) sediment core contained saltmarsh Foraminifera only in the top metre. For the remaining core samples, an open estuary environment could be reconstructed with the help of Ostracoda. This means that a saltmarsh was formed through facilitation succession (Hypothesis 1). A second sediment core was collected and analysed for a master project (Palmisano, 2010), which revealed the same results about the saltmarsh development for the TTI site. From the Gann (G) location, the saltmarsh zones from the three sediment cores indicated for one core a high marsh and for the other two only high to mid marsh conditions, which support Hypothesis 2. From the next study site at Loch Riddon (LR), also three sediment cores were extracted, two from the marsh and one from the mudflat in front of it. The two saltmarsh cores showed a shift in the Foraminiferal assemblages from low to high marsh in both cores from bottom to top, which support Hypothesis 1. The saltmarsh at Kyleakin (KY) contained two sediment cores, where both showed a possible marsh succession from mid to high which supports Hypothesis 1. The last two study sites were neighbouring Lochs on the Isle of Skye. From the Loch Ainort (LA) site, two sediment cores, only one of them from the marsh surface, were collected. The second core was taken from a heather area which was growing on top of a saltmarsh. From this core, saltmarsh zones could only be found in the lower three samples, indicating that the top sample represented a paleo saltmarsh surface. Nonetheless, the marsh succession of both cores showed mid marsh conditions for all samples, which supports Hypothesis 2. From the study site at Loch Sligachan (LS), only one sediment core was extracted which also revealed a mid to low marsh, which supports Hypothesis 2. One sediment core, originally from Holkham (Hol), was re-sampled at the BGS. The Foraminiferal assemblages indicated high marsh conditions for the lowest metre of the core (above a layer of peat), which developed over a mid into a low marsh, and into a high marsh again at the top metre. The already existing data confirms also the same marsh development, which supports Hypothesis 2.

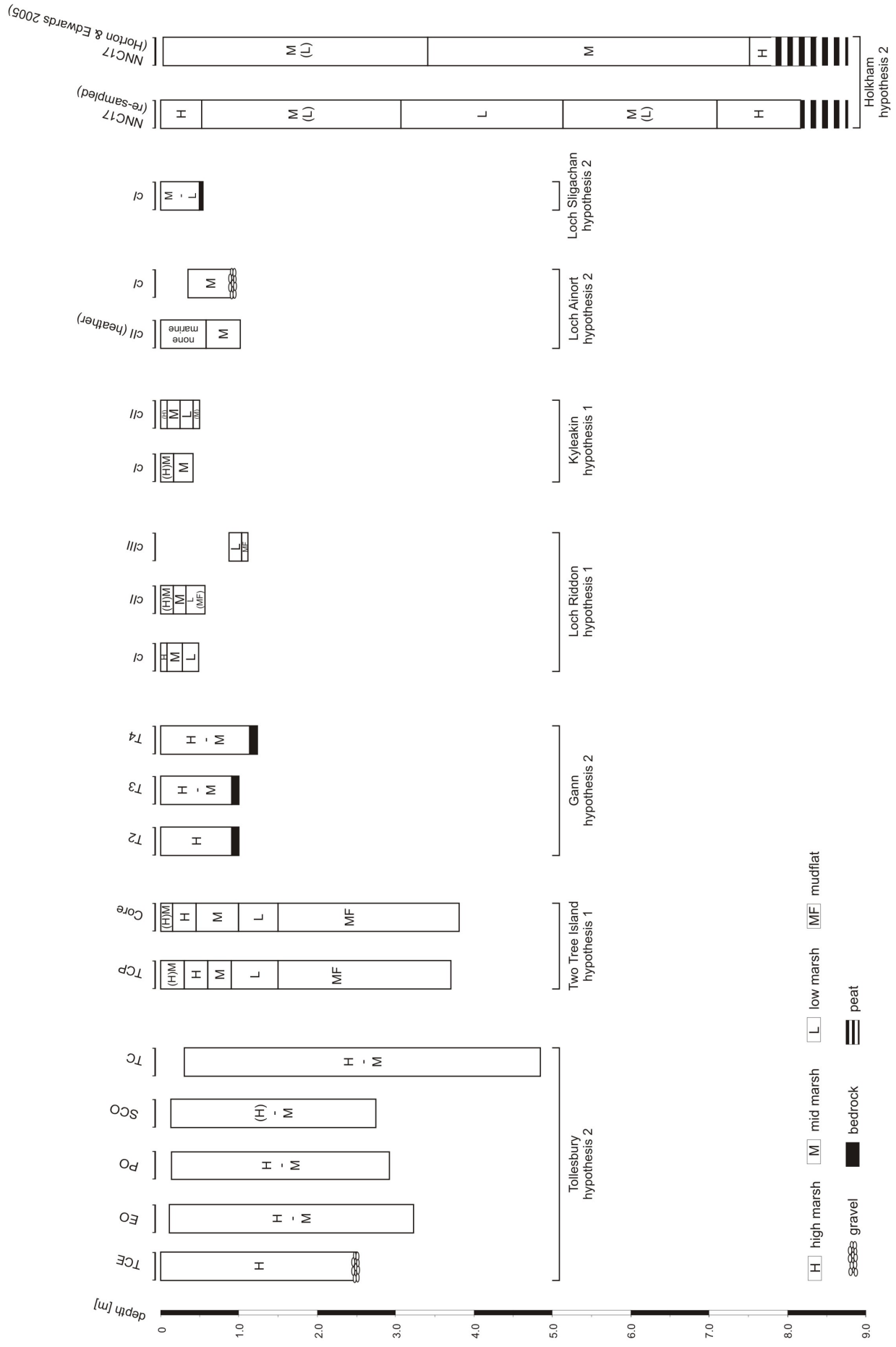


Figure 6.57.: Environmental interpretation of all analysed saltmarsh sediment cores from all study sites which is based on the identified Foraminiferal assemblages. Also shown is the sediment below the marsh if it was encountered. The T, LR, KY and LA cores are also correlated to the elevation of the marsh surface.

It is to mention that not all sediment cores taken reached the bedrock below the marsh (figure 6.57). So, the beginning of the saltmarsh is certain for one Tollesbury core (TCE), all Two Tree Island cores, all Gann cores, one Loch Ainort core (c I) and the Holkham core (NNC 17). This means that for the remaining cores, it is unknown whether the marsh started out with the marsh zone identified for each core or not. The saltmarshes from the cores from Loch Riddon, Kyleakin and Loch Ainort could therefore be deeper. For the Tollesbury site all cores show a similar marsh succession and in combination with the TCE core (which grew on Pleistocene gravel (Greensmith & Tucker, 1973)) it can be assumed that all cores started with the marsh zones they were identified with. The loch head marshes (LR, LA, KY?) on the other hand probably formed on top of the gravel and sand from the rivers and lochs, so the saltmarsh succession can be assumed to be not very deep. This is true for the Loch Ainort core I and the Loch Sligachan core, where both marshes started to grow on gravel or bedrock. Also, Shennan et al. (2006b) shows the Cross-section of the Barr na Criche marsh (west Isle of Skye) which is not deeper than 75 cm with gravel below. However, to confirm this suspicion, a re-sampling would be in order with a stronger corer (e.g. percussion corer) to reach the bedrock or gravel below the marsh.

6.4. Ostracoda analyses from the Isle of Wight saltmarsh

The rare Ostracoda species *Leptocythere malcomsoni* Horne & Robinson, 1985 was formerly thought to be an extinct Pleistocene species. It was originally described as *Loxoconcha cuneiformis* Malcomson, 1886 (the species name being preoccupied by *L. cuneiformis* Terquem, 1885) on the basis of a single Recent specimen from the coast of Ireland, which was subsequently considered to be probably reworked from a Quaternary deposit. However, living populations were found in the mid-1990s on English saltmarshes on the Isle of Wight and in Norfolk (Horne & Boomer, 2000). A newly-discovered saltmarsh population of this species near Tollesbury (T), see chapter 6.3.1, suggests that it may not be as rare as was previously thought. Therefore, a field study was conducted in order to re-collect this Ostracoda species from the saltmarsh at the Western Yar Estuary on the Isle of Wight (IW). There were two sampling campaigns, one in April 2013 and one in April 2014, where the northern part of the estuary, as well as a southern sampling location in 2014, was sampled, see chapter 3.2.3 for map. Table 6.7 gives an overview of all 13 Ostracoda species per sampling location, indicating in which marsh zones they were found. The north IW (2013) sampling campaign contained 13 samples from the low ((R 1, R 2, Aas1 1, Aas 2, L 1, L 2) over mid (Ao 1, Ao 2, SP 2, Ai 1, Ai 2) to high-mid marsh (Mix 1, Mix 2) zones. The north IW (2014) sampling campaign had 7 samples analysed from the low ((R 3, R 4, Aas1 3, Aas 4) and high-mid marsh (Mix 3, Mix 4, Mix 5) zones, which were re-sampled from the previous year. And from the south IW (2014) sampling campaign, three samples were analysed from the high-mid marsh (Mix 6) and high marsh (HL 1, HL 2) zones.

Table 6.7.: List of 13 identified Ostracoda species per marsh zone and three sampling locations (IW north 2013, 2014 and south 2014) from the Isle of Wight (IW). The marsh zones range from low (R 1, R 2, Aas1 1, Aas 2, L 1, L 2, R 3, R 4, Aas 3, Aas 4) over mid (Ao 1, Ao 2, SP 2, Ai 1, Ai 2) to high-mid marsh (Mix 1, Mix 2, Mix 3, Mix 4, Mix 5, Mix 6) and high marsh (HL 1, HL 2).

Ostracoda species	**IW north (2013)**	**IW north (2014)**	**IW south (2014)**
C. torosa	R 2, Aas 2		
H. rubida	R 1, Aas 1 to L 1, SP 2, Ai 1 to Mix 2	Mix 3, Mix 4, Mix 5	Mix 6
L. castanea	Ao 1, Ai 1 toMix 2	R 3 to Mix 4	R 3 to Mix 5
L. ciliata	R 1 to Aas 2, Mix 2	R 3, Aas 4, Mix 5	
L. fabaeformis	R 1, Aas 1	R 3, R 4	
L. porcellanea	R 1, Aas 1 to L 2, Sp 2, Mix 2	R 3 to Mix 3	
H. viridis		R 3	
L. rhomboidea	R 1, L 1		
C. fischeri	Aas 1	R 3	
C. cf. *stephanidesi*	Mix 1, Mix 2	Mix 4	Mix 6
P. trieri	R 1, Aas 2	R 3 to Mix 3, Mix 5	
X. labiata	R 1, Aas 1 to L 2, Ao 1, SP 2, Ai 1	R 3 to Aas 4, Mix 5	
Terrestricythere sp.	Ao 2		HL 1, HL 2

The 13 saltmarsh surface samples in 2013 were extracted from the north site of the estuary, ranging from the low (R 1, R 2, Aas1 1, Aas 2, L 1, L 2) over mid (Ao 1, Ao 2, SP 2, Ai 1, Ai 2) to high-mid marsh (Mix 1, Mix 2) zones. 449 Ostracoda specimens from 12 species were picked: *Cyprideis torosa* (Jones, 1850), *Hemicythere rubida* (Brady 1868), *Leptocythere castanea* (Sars, 1866), *Leptocythere ciliata* Hartmann, 1957, *Leptocythere fabaeformis* (G. W. Müller, 1894), *Leptocythere porcellanea* (Brady, 1869), *Loxoconcha rhomboidea* (Fischer, 1855), *Cytherois fischeri* (Sars, 1866), *Cytherois* cf. *stephanidesi* Klie, 1938, *Paradoxostoma trieri* Horne & Whittaker, 1985, *Xestoleberis labiata* Brady & Robertson, 1874 and *Terrestricythere* sp., see table E.7 for a list of absolute abundance of all species per sample.

The low marsh sample R 1 (marsh plateau edge), contained a high amount of Ostracoda (152 individuals), with *X. labiata* as the most abundant species (47%), see figure 6.58. Also common was *L. castanea* with 28%, *L. porcellanea* with 7% and *L. fabaeformis* with 6%. Sample R 2 contained only one specimen of *L. ciliata*. In the marsh area, where algae was growing on at the marsh rim, the samples Aas 1 and Aas 2 were collected, and

contain 25 and 38 specimens. The sample Aas 1 contained a high abundance of *X. labiata* (40%), and also 28% of

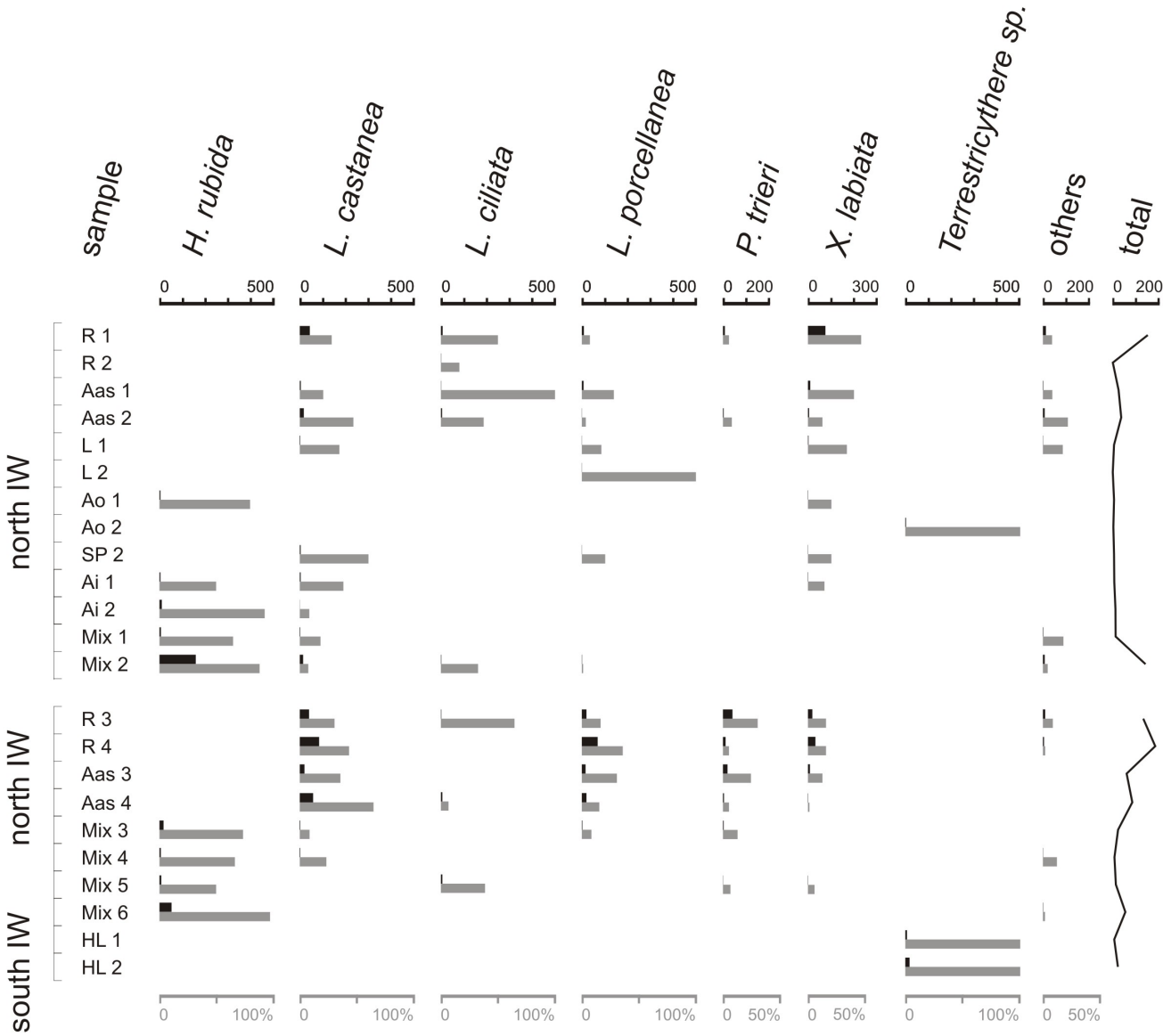


Figure 6.58.: 23 Isle of Wight (IW) saltmarsh surface samples, showing absolute (black bars) and relative (grey bars, %) abundance of the most common Ostracoda species per sample. The top 13 samples (R 1 to Mix 2) were collected from the northern part of the Western Yar Estuary in 2013 from 3 different marsh zones. 7 samples (R 3 to Mix 5), of the re-sampled ones from 2014, were analysed, as well as 3 samples (Mix 6, HL 1, HL 2) from the southern estuary area.

L. porcellanea and 20% of *L. castanea*. Sample Aas 2 showed a similar Ostracoda assemblage as Aas 1, only *L. castanea* was the dominant species (47%), and with each 11% *X. labiata* and *L. fabaeformis* were collected. The low marsh samples (L 1, L 2) only contained 6 and 1 Ostracoda specimens, which were *L. porcellanea* (in both), as well as *L. castanea* and *X. labiata* in L 1. The mid marsh samples Ao 1 and Ao 2, collected from the *Atriplex* of the outer marsh area, showed low Ostracoda assemblages with 5 and 6 specimens. Ao 1 contained *H. rubida* and

X. labiata, whereas sample Ao 2 contained only *Terrestricythere* sp.. Also sediment from a salt pan (SP 2) was collected, revealing a total of 5 specimens, belonging to *L. castanea*, *L. porcellanea* and *X. labiata*. The *Atriplex* from the inner marsh (Ai 1, Ai 2), showed a bit higher Ostracoda abundances than from the outer marsh, 8 and 12 specimens per sample. Both contained *H. rubida* (50 and 95%) and *L. castanea* (38 and 8%). In the former sample *X. labiata* (13%) was also found. The two high-mid marsh samples Mix 1 and Mix 2 were extracted from a *Atriplex* / *Puccinellia* plant zone, and contained 11 and 182 specimens. Both samples had a similar Ostracoda assemblage with *H. rubida* (64 and 88%), *L. castanea* (18 and 7%) and *C.* cf. *stephanidesi* (18 and 4%). No live *L. malcomsoni* nor any valves were found. However, living rare Ostracoda *H. rubida*, *L. fabaeformis* and *X. labiata* were observed, as well as from the remaining three *Leptocythere* species. A living Ostracoda population of *H. rubida* was found in sample Mix 2.

In February 2014, the sample sites from 2013 were re-sampled, and six of these analysed, which were collected from the low (R 3, R 4, Aas 3, Aas 4) and high-mid marsh (Mix 3, Mix 4) zones. Additionally, one sample from a higher high-marsh (Mix 5) location was collected as well. A total of 507 Ostracoda specimens from 10 species were collected: *Hemicythere rubida* (Brady 1868), *Leptocythere castanea* (Sars, 1866), *Leptocythere ciliata* Hartmann, 1957, *Leptocythere fabaeformis* (G. W. Müller, 1894), *Leptocythere porcellanea* (Brady, 1869), *Hirschmannia viridis* (O. F. Müller, 1785), *Cytherois fischeri* (Sars, 1866), *Cytherois* cf. *stephanidesi* Klie, 1938, *Paradoxostoma trieri* Horne & Whittaker, 1985 and *Xestoleberis labiata* Brady & Robertson, 1874, see table E.7 for absolute species numbers per sample. The species *L. fabaeformis*, *H. viridis*, *C. fischeri*, *C.* cf. *stephanidesi* were summarised together with other species in figure 6.58 due to their low abundance per sample.

The re-sampled low marsh samples (R 3 and R 4) contained the 128 and 183 Ostracoda specimens. Both showed a similar assemblage, which contained *L. castanea* (30 and 42%), *L. fabaeformis* (each 2%), *L. porcellanea* (16 and 36%), *P. trieri* (30 and 5%) and *X. labiata* (each 15%). The same Ostracoda assemblage was also identified from the re-sampled low marsh samples Aas 3 and Aas 4, only with lower species abundances, see figure 6.58. Mix 3 and Mix 4 are re-collected samples as well, and contain similar assemblages with 25 and 9 specimens. The identified Ostracoda were *H. rubida* (72 and 67%) and *L. castanea* (8 and 22%). The additional Mix 5 sample contained 18 specimens, with the most common species *H. rubida* (50%) and *L. ciliata* (39%). From all samples, living populations of *P. trieri* (R 3) and *H. rubida* (Mix 6) were observed. And again, no live *L. malcomsoni* nor any valves were found.

From a southern sampling location at the Western Yar Estuary, seven saltmarsh surface samples were collected and three analysed, which were from the high-mid marsh (Mix 6) and high marsh (HL 1 and HL 2). 80 Ostracoda specimens from three species were found: *Hemicythere rubida* (Brady 1868), *Cytherois* cf. *stephanidesi* Klie, 1938, *Terrestricythere* sp., see table E.7 for the absolute abundance of all species per sample.

The high-mid marsh sample Mix 6 contained 51 individuals of *H. rubida* (live population) and one *C.* cf. *stephanidesi*. The two high marsh samples (HL 1 and HL 2), consisting also of leave litter from a nearby oak tree, contained only *Terrestricythere* sp. with 8 and 20 specimens. A living population of *Terrestricythere* sp. was observed in sample HL 2.

The conducted Ostracoda study on the Isle of Wight, revealed the absence of *L. malcomsoni*, even though a population was found from the same saltmarsh location at the Western Yar Estuary in October 1995 (Horne & Boomer, 2000). From each visible plant zone, surface samples were collected, but the results show that only three samples from 13 contained high abundances of Ostracoda (chapter 6.4). However, three rare Ostracoda species were found at this saltmarsh: *Leptocythere fabaeformis* (G. W. Müller, 1894), *Hemicythere rubida* (Brady 1868) and *Xestoleberis labiata* Brady & Robertson, 1874. From *H. rubida* and *X. labiata* living populations have been found. Also, single living *L. fabaeformis* were found, but no population. From the re-sampled surface samples of the following year, only the samples which showed higher Ostracoda abundances from the previous year were analysed. Additional, surface samples were also collected from a second location farther south (chapter 3.2.3). Here, *Terrestricythere* sp. was identified on the high marsh crawling on leaves from a nearby oak tree.

7. Age Dating of Saltmarsh Sediment Cores

Different age dating techniques are widely used to determine the history of a study site. It was necessary in this study to determine the age of the sediment where the microfossil assemblages were found to reconstruct the saltmarsh development in correlation to the known and dated relative sea-level changes. In this chapter four dating methods are described that were used: radiocarbon, caesium and lead dating, as well as optically stimulated luminescence (OSL). From the first two methods it is known of their successful use on marsh sediment, whereas OSL is new and will be tested in this study by correlating it to the other two methods.

7.1. Introduction to Quaternary age dating techniques

The current and most recent geological period is the Quaternary, which spans from 2.5 million years until present time and includes the two epochs Pleistocene and Holocene. Even though it is often viewed to be synonymous with the *Ice Age*, the Quaternary represents the repeated oscillation of glacial and interglacial states (Walker, 2005). These states are influenced by the global climate which is considered to be driven by the astronomical Milankovitch cycles (Lowe & Walker, 1997). Using the astronomical time scale was one of the earlier approaches to dating the past with its events, the four major glacial episodes, which led to the introduction of the glacial interglacial chronology. Then, with using laminated sediments (varves), the basis for Quaternary chronology was established which is still in use, as is tree-ring dating or dendrochronology (Walker, 2005). Then, during World War II, a significant development was the use of the radioactive decay of certain elements as a basis for dating. Then, radiocarbon dating and later other radiometric methods were used for a more accurate dating. And with the developing technology came fission track, thermoluminescence and electron spin resonance dating techniques. Walker (2005) represents an overview and description of all the different Quaternary dating methods, including those that are not mentioned here, as this list is too extensive to be included here. Only the four dating techniques that were used in this study will be described: radiocarbon, caesium and lead dating, as well as luminescence dating.

Radiocarbon dating

The most widely used dating technique of all radiometric methods is radiocarbon dating. It is based on the decay of the element carbon-14 (^{14}C) which is a radioactive isotope with a half life of $5\,730 \pm 40$ years (Walker, 2005). There are three carbon isotopes, the other two are ^{12}C and ^{13}C, which are stable. The ^{14}C atoms are formed in the upper atmosphere through the decay of the Nitrogen isotope ^{14}N. Then in combination with oxygen becomes carbon dioxide (CO_2) over which it is integrated into the global carbon circle. Then, it is absorbed by plants over photosynthesis and stored in animal tissues when they consume the plants. When the organism dies, the ^{14}C will no longer be ingested and the radioactive isotope decays at a constant rate. Then, by comparing a ^{14}C standard with the one from the sample, the date of death of the organism can then be determined (Walker, 2005). The dates are then expressed in radiocarbon years before present (BP).

Caesium & lead dating

In contrast, caesium-137 (^{137}Cs) and lead-210 (^{210}Pb) represent short-lived radioactive isotopes with half lives of 30.17 years and 22.3 years (Walker, 2005). Caesium-137 is an artificial radioactive isotope that has been produced by nuclear weapons tests. It showed an atmospheric increase in 1954 and peaked in 1963, after then it declined. This maximum in 1963 forms a distinct marker horizon which can then be used to date sediment layers. Another peak in 1986 also may occur, indicating the Chernobyl fallout (Walker, 2005). In the UK, a third peak from 1975 from the BNFL Sellafield can also show in the measured ^{137}Cs curve, but is mostly restricted to the west coast of the UK (Teasdale et al., 2011).

^{210}Pb is a naturally occurring isotope and can be used to date within 1 to at least 150 years time range. It is part of the uranium decay chain where the decay in the sediment takes place in situ (supported ^{210}Pb). A second ^{210}Pb source is the decay of the radon gas (^{222}Rs) which as atmospheric fall-out produces the excess ^{210}Pb in sediments. Therefore, when measuring the amount of ^{210}Pb it comprises both supported (bs) and excess (xs) ^{210}Pb. By determining the excess ^{210}Pb in the sediment, its radioactive decay curve can be used for dating the sediment (Walker, 2005). There are thee ^{210}Pb models used to determine the sedimentation rate (age) (Spencer, 1999), see chapter 7.2.3.

Luminescence dating

Luminescence dating also belongs to the radiometric methods, where the radiation exposure of a mineral can be used for dating when it was buried. When exposing minerals to ionizing radiation, electrons can be trapped in defects in the crystal structure. When releasing these electrons from the traps, energy is created in form of light which can be measured (Walker, 2005). For this method to work, the minerals should have traps that can be easily emptied by sunlight exposure and also be thermally stable to keep all trapped electrons over time. After

incorporating the minerals in the sediment, the ionizing radiation comes from the decay of radioactive isotopes of rubidium, potassium and the ones from the uranium and thorium decay chains. Therefore, the minerals receive doses from different radiation types. By comparing the luminescence signal from the natural state of the minerals with that induced in the minerals by exposure to a radioactivity source in the laboratory (beta emission from a $^{90}Sr/^{90}Y$ source), the total radiation dose of the minerals can be identified. This measured dose is the *equivalent dose* (D_e) (Wintle, 2008). There are different methods on how the electrons are freed from their traps to gain the luminescence signal, mostly either by heat (thermoluminescence - TL) or by light exposure (optically stimulated luminescence - OSL) (Walker, 2005). Here, optically stimulated luminescence (OSL) will be used due to the available laboratory equipment. Then with the luminescence signal a dose-response curve (growth curve) can be constructed and the age calculated (Boomer & Horton, 2006). Walker (2005) gives a good overview of all the different luminescence dating techniques and their application.

7.1.1. Aim of dating saltmarsh sediment

This study focuses on saltmarsh development during the Holocene, as described in chapter 1. For reconstructing marsh developments, sediment cores from several UK saltmarshes were extracted and their meiofauna (Foraminifera and Ostracoda) assemblages analysed. In doing so, marsh zones could then be identified within the sediment cores, indicating changes in the environment, but most likely reflecting relative sea-level fluctuations, see chapter 1.4. However, without knowing the age of the sediment cores, no correlation with the known relative sea-level curves would be possible. Also, by dating the sediment, the sedimentation rate could be calculated.

Therefore, four different age dating methods were used: radiocarbon (^{14}C), optically stimulated luminescence (OSL) and caesium & lead dating (^{137}Cs, ^{210}Pb). These were used to identify the age of the saltmarsh, but also to calculate the sedimentation rate. Due to high costs and time consuming sample preparations, only two sediment cores (c II, c IV) from Tollesbury were dated. However, because four dating methods were used, the ages and sedimentation rates can be correlated with each other to gain more accrue results. For other study sites, the marsh age was extracted from literature if it was available.

7.2. Methods

Three different age dating methods were used: radiocarbon (^{14}C), optically stimulated luminescence (OSL) and caesium & lead dating (^{137}Cs & ^{210}Pb). The first two techniques were conducted on a 4 m long sediment core (c II), which was extracted in 2012, and the last one on a 1 m long (c IV) sediment core extracted in 2013 from the Tollesbury saltmarsh, Essex, south-east England.

7.2.1. Tollesbury sediment cores

Two sediment cores (TCE and c II) were used to date the saltmarsh sediment to determine the age of the marsh at Tollesbury.

Extraction

The 4 m long saltmarsh sediment core (c II) was extracted with a percussion corer and liner sampler. For the exact location and position of the coring sport, see chapter 3.2.1, figure 3.2. It took four people to carry and mount the corer in the field. The coring equipment included several pieces for first, pushing a round cylindrical and hollow metal case into the ground. In each case, a hard plastic tube (liner) was embedded for a better sediment removal afterwards. And secondly, to extract this metal case when it was filled with the sediment, see figure 7.1. Four attempts were necessary to get in total a 4 m long core, with 1 m long and 6 cm diameter sections each. All work had to be carried out by low tide on the marsh surface and at least four persons were needed to handle the equipment.

(a) Percussion corer

(b) Extraction of coring tube

Figure 7.1.: Photos showing the process of coring with a percussion corer at Tollesbury saltmarsh by low tide (a) Percussion corer: tow people are required to hold the 60 kg heavy corer above the metal case which is pushed down into the sediment, and (b) Extraction of coring case: again, two people are necessary to pull up the metal case with the marsh sediment.

The second sediment core of 1 m length (c IV), was taken in a one metre distance from the c II sediment core. For the exact core location, see map in chapter 3.2.1, figure 3.2. The extraction of the sediment was done with a cylindrical and hollow hard plastic tube of 1.2 m length and 19 cm in diameter. It was vertically positioned on the marsh surface, then a 5 cm cm thick wood panel was placed on top the upper opening so that the tube could

be pushed into the ground with a hammer. When the plastic tube was 1 m deep in the ground, the outer sediment had to be excavated in order to extract the filled tube. This process had also to be done during low tide.

Sampling

The sampling of the c II core was done first in a dark room to sample the needed sediment for the OSL technique. For this, the four 1 m long plastic tubes (figure 7.2) were cut open in the middle to reach the sediment. Then, six 10 cm sections from 20 to 30 cm (Tol 1), 90 to 100 cm (Tol 2), 170 to 180 cm (Tol 3), 210 to 220 cm (Tol 4), 290 to 300 cm (Tol 5) and 370 to 380 cm (Tol 6) depths were extracted. The outer rim of each sediment section was removed, dried by 60°C in an oven, and pulverised for measuring the dosage for each sample. The water content from each sample was measured as well. The remaining sediment was cut in half and stored for sample preparation before age dating measurements could start. Second, for the radiocarbon dating, the sampling on this core was done by daylight. Due to the C14 CRONO Dating Award, three samples were taken. For each one, black plant remains were extracted with tweezers so that from 195 to 200 cm (T 1) depth 104 mg, from 270 to 280 cm (T 2) depth 74 mg, and from 350 to 360 cm (T 3) depth 68 mg amounts of sediment and plants (bulk) were sampled. These were sealed in 10% HCl cleaned plastic tubes and shipped off to be measured at the Queen's University Belfast (UK).

For extracting the samples for the caesium & lead dating, the 1 m long c IV sediment core was carried back to the laboratory where the plastic tube was cut open. The sediment inside was 96 cm long and had a diameter of 18.5 cm (figure 7.2). Then, the whole sediment block was sliced into 2 cm thick discs, each of them weighted, dried by 60°C in an oven, and then weighted again for water content measurements. From each 48 samples, between 72.6 and 265.6 g of dried sediment was warped in plastic and shipped off to be measured at the Georg-August-Universität Göttingen (Germany).

7.2.2. Radiocarbon dating (^{14}C)

For the radiocarbon dating, the method used extracted humic acids, as described in Lowe et al. 2004, and was conducted on all three radiocarbon samples (T 1, T 2, T 3) from the Tollesbury saltmarsh sediment core (c II). For measuring the radiocarbon age, the calibration dataset of Reimer et al. (2009) was used, and done at Queen's University Belfast. The measured radiocarbon dates were then calculated and expressed in radiocarbon years before present (Cal BP).

7.2.3. Caesium & lead dating (^{137}Cs & ^{210}Pb)

The measurement of the caesium and lead was done in the Laboratory for Radioisotopes (LARI) at Georg-August-Universität Göttingen, Germany. Here, gamma-ray spectroscopy was used for measuring the ^{137}Cs and ^{210}Pb of

(a) 4 m long core (c II)

(b) 1 m long core (c IV)

Figure 7.2.: Photos showing both saltmarsh sediment cores which were extracted for age dating (a) 4 m long core (c II): each 1 m long section filled with brown sediment, from top (right) to bottom (left) still enclosed by plastic to prevent contamination and better transportation, and (b) 1 m long core (c IV): cut open tube with an embedded 96 cm long sediment block, where the top (right) is a dark brown to black and the bottom (left) a light brown colour.

each sample. The dried sediment (approximately 120 g per sample) was measured for a minimum counting time of 250 000 seconds using a low-background coaxial Ge(Li)detector (Schuerch et al., 2012). The ^{137}Cs of each sample had to be normalised to the mean percentage of grain sizes smaller than 20 µm of the whole core and mean organic matter content due to its affinity to sorb itself onto small particles (Kirchner & Ehlers, 1998). With the known start of the accumulation of the artificial ^{137}Cs in the atmosphere at 1954 and the two other peaks at 1963 and 1986, the sedimentation rate could also be calculated (Walker, 2005).

For the ^{210}Pb, one model (A) was used to determine the sedimentation rate, whereas two other models (B and C) were used date the sediment. The first model (A), Simple model, assumes that a constant sedimentation rate takes place and when plotting the ln of ^{210}Pbxs (natural log of activity) against depth, the resulting profile will be linear. Then the sedimentation rate (r) can be calculated over the gradient of the line = λ/r (λ ^{210}Pb = 0.03114). The second model (B), constant initial concentration model (CIC), assumes that most of the ^{210}Pb is supplied to the sediment. So, an increase in sedimentation rate will therefore result in an increase in the ^{210}Pb activity. By using the formula $C = C_0 e^{\lambda t}$, an age for each depth can be calculated. The third model (C), constant rate of supply model (CRS), assumes that the rate of supply of ^{210}Pb is constant regardless of changes in sediment input. The dominant supply of ^{210}Pb is atmospheric. Therefore, an increase in sediment input results in a decrease in the ^{210}Pb activity in the sediment (Spencer, 1999; Walker, 2005).

7.2.4. Optically Stimulated Luminescence (OSL)

For the optically stimulated luminescence analyses six sediment samples (Tol 1, Tol 2, Tol 3, Tol 4, Tol 5, Tol 6), from the Tollesbury sediment saltmarsh core (c II), had to be prepared before the radiation dose (GY) could be measured and the age calculated. This involved several steps which were the same for each sample. First, the sediment sample, which was roughly 5 x 5 x 2-3 cm in size had to be broken down into smaller pieces and placed in a 150 ml beaker, filling approximately half of it. Then, 10 % hydrogen chloride (HCl) was added until the sample was covered with the acid. The sample stirred with a spatula under a fume cupboard and kept there for one night. The next day, the remaining fluid in the beaker was decanted and distilled water added, stirred and let to rest for at least 2 hours until no sediment was in suspension. The clear fluid was then decanted and this process, of adding distilled water and decanting it, repeated two more times. After this, 30 % (H_2O_2) was added to the sample, stirred and let to rest under the fume cupboard over-night again. To prevent any contamination because of possible volatile reactions due to the acid, the beaker was covered with paper. On the next day, the remaining acid was, like the one before, decanted and three times distilled water was added and after 2 hours decanted again. Afterwards, sodium oxalat ($C_2Na_2O_4$) was added to the sample to prevent particle clumping, as well as the whole beaker was dipped in an ultrasonic bath for at least 5 minutes to get the sediment in suspension.

Then, secondly, an Atterberg cylinder (tall 4 litre cylinder with outlet in the middle) was used to extract the desired sediment particle size. For this, distilled water was used and half of the cylinder filled with it, and let to rest over night so that the water temperature was the same as room temperature. This was done, because the temperature could influence the settling time of the finer sediment particles in the water column of the Atterberg cylinder. The dispensed sediment sample was then added to the water in the Atterberg cylinder and the settling sediment observed and timed, so that after 40 seconds, the desired particle size could be extracted over an outlet in the cylinder. After several tests, it was decided that the 16 to 35 µm fraction of all sediment samples were used, because not enough of the smaller one was present in all samples. And 35 µm was the upper limit for measuring the radiation dose of the fine fraction. The extraction of the 35 µm fraction and smaller was then repeated five times, and the siphoned water with suspended sediment put in a 500 ml beaker.

Thirdly, the extracted water sediment mix was then filled in eight plastic tubes, up to the 40 ml mark and spun in a centrifuge with 200 spins for one minute to get the 16 to 35 µm sediment fraction. The 16 to 35 µm sediment size was settled at the bottom of each tube after each minute, so that the remaining water with the finer sediment fraction in suspension could be decanted from the tubes. New distilled water was added and the centrifuge process repeated until the water in the tube was clear and the desired sediment settled at the bottom. The extracted sediment with the fraction of 16 to 35 µm was then be removed into a 150 Im beaker and dried in

an oven by 60°C. The dried sample was then filled in small labelled glass tubes and stored in light proof tubes to keep the sample dark and prevent any light contamination.

After these preparation steps, the sediment of three samples (Tol 2, Tol 3, Tol 4) was used to determine if enough quartz was present in them for possible radiation dose measurements. For this, with great care hydrofluoric acid (HF) was added and let to rest for one week. Then, the acid was decanted, neutralised and the sediment samples rinsed with distilled water and decanted four times. Afterwards, 10 % HCl was added and the samples rested for one day. Next, this acid was decanted and distilled water added before decanting three times. The same was done once with acetone and then the samples were dried in an oven by 60 °C. This process revealed that not enough quartz was present in all samples to be used, and therefore it was decided to use the whole sediment of the sample as a polymineral (PM) sample.

The last preparation step, was to put the dried sediment with the 16 to 35 µm polymineral fraction onto metal disks. Stainless steel disks (50 for each sample) were put in glass tubes with the same diameter and put in a wooden holder which was placed under a fume cupboard. In a beaker, for 50 disks, 150 mg of the sediment sample (approximately 3 mg per sample) was weighted out and 50 ml of acetone added. The whole beaker was dipped in an ultrasonic bath for at least 2 minutes until all sediment was in suspension. Then with a 1000 ml hand pipette, the suspension was filled in each glass tube onto the disks and dried over-night. The next day, the disks were coated with a film of the sediment sample and placed into labelled metal cases for storage until the samples were measured.

The measurement of the radiation dose of each sample was done with a machine, TL/OSL-DA-15 reader, at QMUL where the disks were placed in a revolver-like disk and an infra-red (IR) filter was used for measuring the dose (GY) of the feldspars in the PM samples. The exact machine settings for each sample will have to be determined once the machine is functioning again, since its ^{90}Sr/^{90}Y source was damaged.

For measuring the equivalent dose of each sample, approximately 100 g of pulverised sediment per sample was sent off to be measured at University of Bern.

7.3. Results

From two Tollesbury saltmarsh sediment cores (c II, c IV), the results of four different age dating methods are presented. They include not only data about the sediment age and sedimentation rate, but also water content analysis of at least one sediment core (c IV). For the used methods, see chapter 7.2, and a list of all data used here can be found in the appendix H.

7.3.1. Radiocarbon dating (^{14}C)

The top 20 cm of the 4 m long Tollesbury saltmarsh sediment core (c II) was brownish in colour due to oxidation and enriched plant horizons / lenses, roots were found as well. The continuing sediment was an unlaminated, greyish-blue silty clay which changed to a sandy silt at 3.5 m depth. For cross-calibration with the OSL dates, radiocarbon dates were needed. Therefore, three samples (T 1, T 2, T 3) consisting of plant remains were analysed (table 7.1) via extracted humic acids, see chapter 7.2.2 for methods.

At a depth of 195-200 cm the plant sample T 1 was dated to 3267 ± 67 Cal BP (UBA-23424). This plant horizon was also identified in a nearby 2.5 m core at the same depth. At 270-280 cm depth (T 2) the plant material was dated to 3843 ± 88 Cal BP (UBA-23425). The water content drops below 30%. The sample (T 3) from 350-360 cm depth was dated to 4967 ± 65 Cal BP (UBA-23426), see figure 7.4. There, the sediment was nearly water free, extreme dense and plant remains were very sparse, but roots were still present (Radl, 2014).

Table 7.1.: Measured and calculated radiocarbon results (^{14}C) for three sediment saltmarsh samples (T 1 to T 3) from a 4 m long sediment core (c II) from Tollesbury, south-east England. Also, the depth of each sample as well as their composition is listed.

Sample name	Sample depth [cm]	material type	sample weight [mg]	radiocarbon BP age	± radiocarbon age BP error	calculated BP age	± calculated age BP error
T 1 (UBA-23424)	195-200 cm	plant remains	104	3005	29	3267	67
T 2 (UBA-23425)	270-280 cm	plant remains	74	3502	34	3843	88
T 3 (UBA-23426)	350-360 cm	plant remains	68	4321	34	4967	65

The calculated sedimentation rate of the sediment core (c II) differs between each radiocarbon sample. Between sample T 3 and T 2, 70 cm of sediment was accumulated over a time period of 1124 ± 23 Cal BP, with a sedimentation rate of 1.61 mm per year. Between sample T 2 and T 1, also 70 cm of sediment was accumulated over a time period of 576 ± 21 Cal BP, with a sedimentation rate of 0.82 mm per year. Between the sample T 1

and the marsh surface, 195 cm of sediment was accumulated over a time period of 3267 ± 67 Cal BP, with a sedimentation rate of 1.67 mm per year.

7.3.2. Caesium & lead dating (^{137}Cs & ^{210}Pb)

The Tollesbury saltmarsh sediment core (c IV) consists mainly of unlaminated greyish silt, with an oxidised brownish part in the top 10 cm of the core. With increasing depth, the clay content increases and a distinct silty clay layer was identified at 28 cm which continued throughout the core, only with additional gravel (4 cm diameter) between 66 and 80 cm depth.

The top sediment core sample contained 63.5% water, and increased until it peaked with 71.9% between 12 to 14 cm depth, see figure 7.3. Then, the water content declined gradually until a minimum was reached with 27.6% at 70 cm depth. Below this depth, the water content remained nearly stable around 35%.

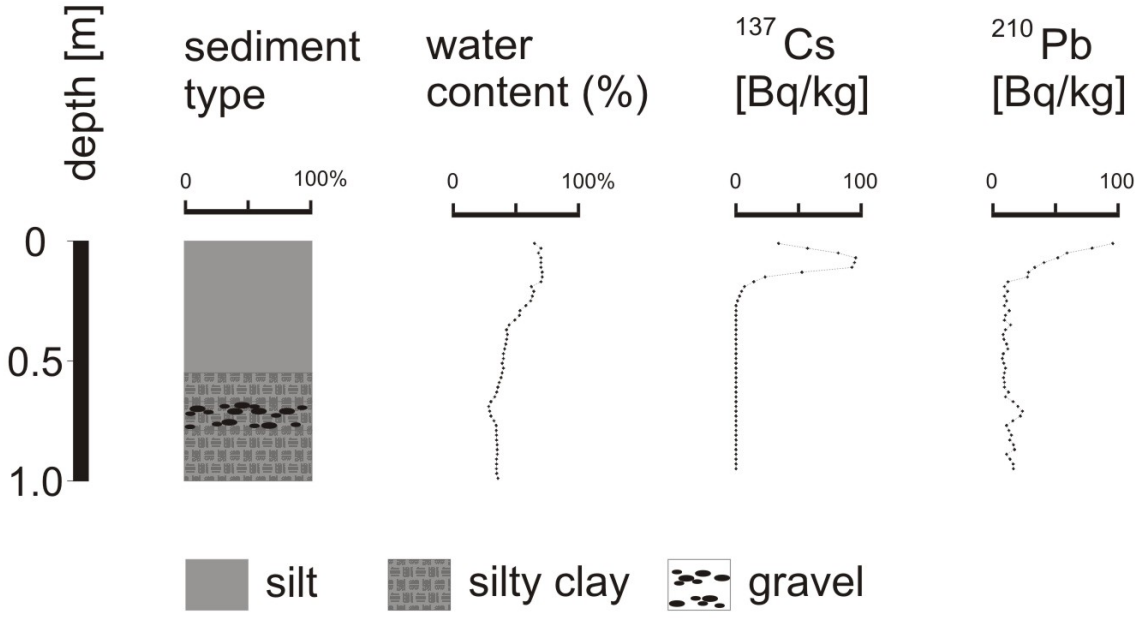


Figure 7.3.: 1 m long Tollesbury saltmarsh sediment core (c IV) showing sediment type, water content (%) and ^{137}Cs and ^{210}Pb activity in [Bq / kg].

The ^{137}Cs activity at the top sediment core sample (1) started with 34.43 Bq / kg, and showed an increase until it peaked between 6 to 8 cm depth with 96.03 Bq / kg (sample 4). The following two samples (5 and 6) also showed increased activity of 94.52 and 93.85 Bq / kg. Then the measured ^{137}Cs activity declines until the lowest sample at 26 cm depth only showed an activity of 1.98 Bq / kg (sample 13). For the remaining samples below 26 cm depth, only background ^{137}Cs activity was measured.

Then, with help of the ^{137}Cs activity, the sedimentation rate of the top 26 cm sediment of the core could be calculated. Between the peak (from 1963) and the lowest ^{137}Cs activity values (from 1954), 19 cm of sediment

was accumulated over a time period of 9 years. The sedimentation rate between sample 4 and 13 was 0.047 mm per year. Between sample 4 and the marsh surface, 7 cm of sediment was accumulated over a time period of 50 years, with a sedimentation rate of 0.71 mm per year. The average sedimentation rate for the whole sediment core was calculated with 0.26 mm per year.

The ^{210}Pb activity showed its highest value at the top sample (1) with 96.0 Bq/kg. The next sample (2) at 2 to 4 cm depth also had an increased activity of 79.11 Bq/kg. Then the ^{210}Pb activity gradually declines to the lowest measured ^{210}Pb activity with 12.17 Bq/kg at 18 cm depth (sample 9). The remaining samples below 18 cm depth, only background ^{210}Pb activity was measured.

The ^{210}Pb values were then used to calculate the sedimentation rate (model A) and sediment age (model B and C). Simple model (A): The result of the plotted ln ^{210}Pbxs values showed a best fit line with a gradient of -0.1559. Then, in combination with the decay constant for ^{210}Pb (λ = 0.03114), the sedimentation rate (r) of 0.1997 mm per year was calculated. Model B and C were then used to calculate the sedimentation age per sample, see table 7.2 for the results.

Table 7.2.: Table showing the top 18 cm with its nine samples of the 1 m long Tollesbury saltmarsh sediment core (c IV) with the ^{210}Pb values. Also, the calculated sediment ages of the CIC model (B) and CRS model (C) are shown.

Sample name	Sample depth [cm]	Pb activity [Bq/kg]	CIC model (years)	CRS model (years)
1	0-2 cm	96.00	-48.47214	0.00000
2	2-4 cm	79.11	-41.69901	7.13768
3	4-6 cm	59.93	-29.77432	18.46507
4	6-8 cm	52.45	-20.31222	30.15720
5	8-10 cm	41.56	-8.14070	42.36935
6	10-12 cm	34.96	6.38438	55.63169
7	12-14 cm	28.97	11.58912	68.10276
8	14-16 cm	28.06	12.30156	84.46427
9	16-18 cm	12.17	33.84819	118.82034

7.3.3. Optically Stimulated Luminescence (OSL)

The machine had a problem with the ^{90}Sr source, and was not functioning properly. Therefore, there are no OSL data available at present. As soon at the machine is repaired, new measurement will be done, since all samples show at least a signal which gives hope that conclusive data will arise.

7.4. Discussion

From the four dating methods, the data of three are described here, since the OSL technique yielded no results so far. The dated sediment from the Tollesbury saltmarsh in combination with the Foraminifera abundances from another sediment core will be compared.

7.4.1. Radiocarbon dating (^{14}C)

The radiocarbon dated core sediments (c II) from the saltmarsh near Tollesbury indicate that the saltmarsh was formed over 4967 ± 65 Cal BP ago. This can be assumed because a 5 m core (TC) from the same marsh contains saltmarsh foraminifera (chapter 6.3.1) throughout and the grain size analysis of the c II core shows similar results, see figure 7.4. This means that the marsh is older than the assumed 4 000 years BP due to archaeological findings from the Essex coast (Wilkinson & Murphy, 1986). All three dates also show that the growth rate of the marsh between T 3 and T 2 was 1.6 mm per year, then between T 2 and T 1 it slowed down to 0.8 mm per year, only to reach again a calculated accretion rate of 1.6 mm per year for the upper 195 cm.

The additional OSL samples in combination with the found Foraminifera would have divide the core into more sections where transgressions and regressions can be identified, dated and marsh development can be reconstructed regarding relative sea-level fluctuations. Also correlations with the Holocene stratigraphy from the southern Crouch estuary will be possible where a saltmarsh core show a similar age of 4100 ± 70 years BP (Wilkinson & Murphy, 1986).

When comparing the dated sediment with the saltmarsh Foraminifera from the TCE core from Tollesbury, the most recent age (3267 ± 67 Cal BP) shows a correlation with an increasing trend of the overall Foraminiferal assemblage at 2 m depth. The lowest absolute abundance of Foraminifera specimens per sample above the 2 m depth, can now be correlated to a drop in relative sea-level (Greensmith & Tucker, 1973) at approximately the same time period as shown in figure 1.5. This means that the absolute amount of Foraminifera specimens from the TCE sediment core show a clear relative sea-level signal.

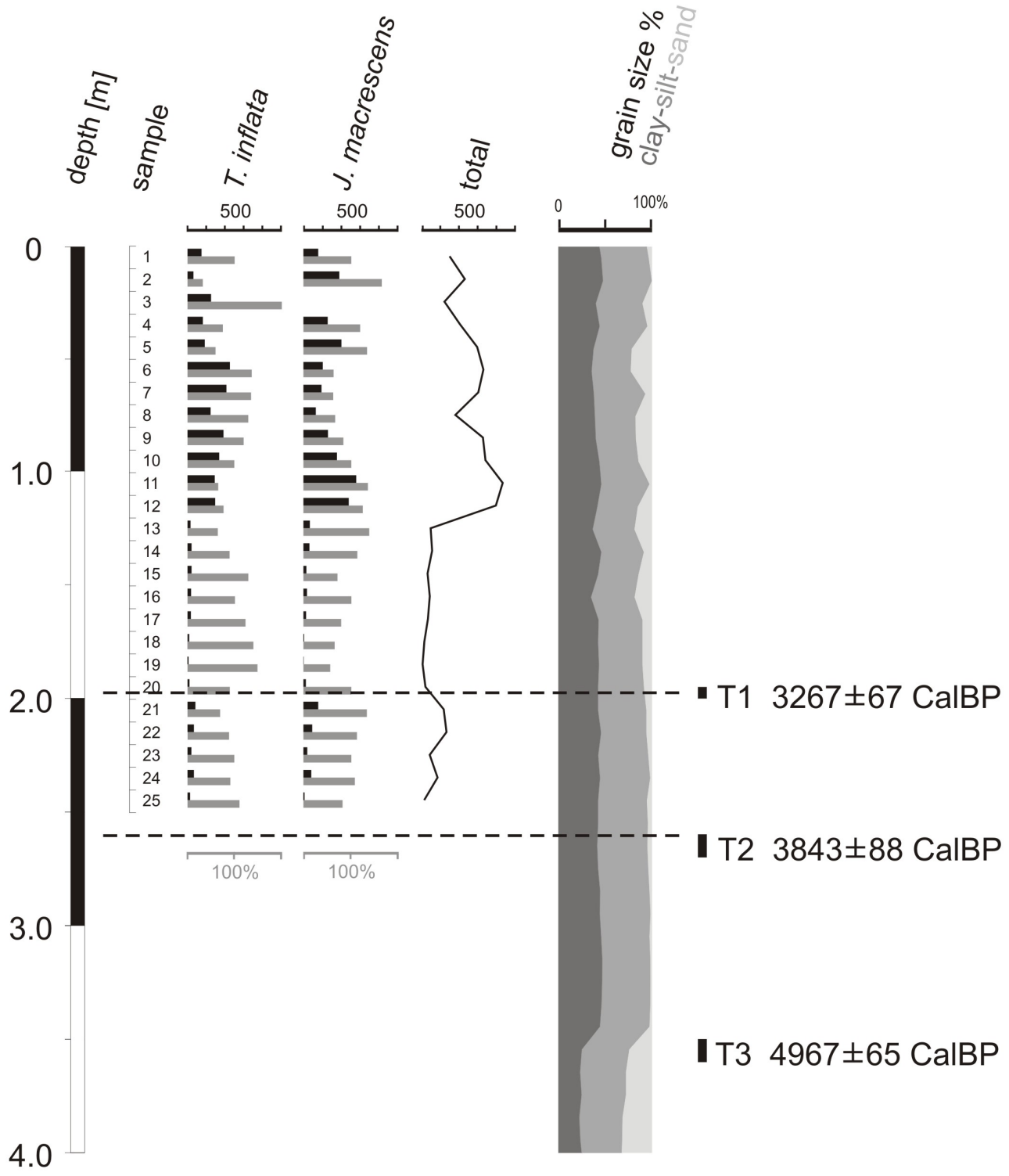


Figure 7.4.: 4 m long Tollesbury saltmarsh sediment core (c II) showing grain size distribution (%) (clay = dark grey, silt = medium grey, silt = light grey) and the samples with their respective depth and calculated radiocarbon age in years BP. Also, TCE Tollesbury 2.5 m deep saltmarsh core with its Foraminiferal assemblages per sample, shown in absolute (black bars) and relative (%, grey bars) abundances.

7.4.2. Caesium & lead dating (^{137}Cs & ^{210}Pb)

The ^{137}Cs values for the c IV Tollesbury sediment core show similar ^{137}Cs results from another sediment core (S2) from Old Hall Marsh also near Tollesbury (Pye, 2000), see figure 7.5. This also means that the sediment at 26 cm depth accumulated 59 years ago.

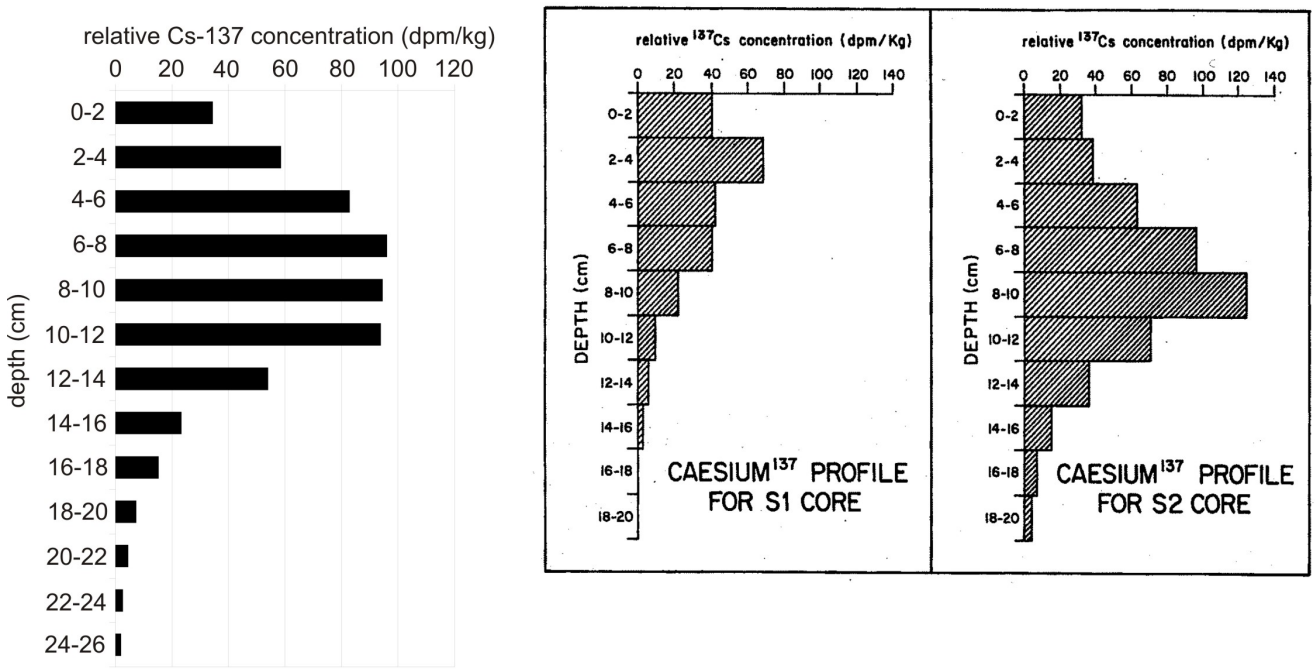


Figure 7.5.: ^{137}Cs data for two saltmarsh sediment cores from the Old Hall Marsh, Tollesbury, west of the managed realignment site. Figure copied from Pye (2000). S1 was extracted from the inner, and S2 from a middle marsh area, which reflect different sedimentation rates.

Compared to ^{137}Cs, the results of the ^{210}Pb CRS model shows an older sediment age (118 years) for the sediment at 18 cm depth. The CIC model did not produce any conclusive results due to negative values, see table 7.2. However, given that the ^{137}Cs data from Old Hall Marsh reveal the same results as the measured ^{137}Cs in this study, it can be safely assumed, that the ^{210}Pb are not correct.

8. Dissolution Experiment

The problem of the taphonomic process is selective preservation (dissolution) which is discussed in this chapter, since it is imperative to understand how calcareous shells preserve in the acidic marsh sediment. Therefore, extracted water from the Tollesbury marsh was used to conduct an experiment over 6 months on calcareous and agglutinated Foraminifera to identify the dissolution processes. Furthermore, SEM images of the Foraminifera tests after the experiment were made to observe any traces of dissolution on their surface. Additionally, the PSA samples (chapter 6) were used to produce glass slides to investigate the presence or absence of diatoms (algae) in the saltmarsh sediment cores. They could be used as an alternative to calcareous microfossils due to their robust silicate shells.

8.1. Overview of Foraminifera test preservation

The most common taphonomic processes are transportation and destruction (abrasion, corrosion) of shells (Haslett, 2000). Calcareous micro-organisms are known to be prone to these processes when dead. This is also true for Foraminifera, but when buried in the sediment, not much post-mortem transportation occurs, as shown in various studies (Gupta, 1999). Then, only bioturbation and diagentic processes affect Foraminiferal assemblages. When the tests are broken, chemical processes like dissolution for example can affect calcareous tests by weakening the areas around cracks and pores. This happens when the pH of the sediment pore-water is or becomes acidic (Haslett, 2000). Normally, dissolution is indicated by opaque, white and etched tests when partial dissolution occurs, the whole shell is lost only in extreme cases (Murray, 1973; Murray, 2006). Also, agglutinated Foraminifera can be destroyed either through bacterial degradation and / or the dissolution of their organic and calcareous cements (Haslett, 2000). When the Foraminifera are alive they can rebuild their tests within 2 days as shown in experiments (Bradshaw, 1961). However, so far, not many studies on dissolution effects on Foraminifera have been conducted (Gupta, 1999). Even fewer deal with the influence of pore-seawater pH on Foraminifera tests and those that have often focus on the pH effects on only one calcareous Foraminifera, e.g. the species *Ammonia beccarii* (le Cadre et al., 2003). Furthermore, in laboratory studies the application of artificial acidic solutions is used, e.g. adding hydrogen chloride (HCl) or sodium hydroxide (NaOH) to seawater until the desired pH is reached (Bradshaw, 1961). Therefore, it is imperative to conduct more studies to investigate the dissolution ef-

fects on (post-mortem) different Foraminifera species. Moreover, if possible, the acidic solutions used in those experiments should imitate the ones from a natural habitat, for example making water acidic by dissolving carbon dioxide (CO_2) gas in it.

8.1.1. Aim of the dissolution experiment

In this study, all analysed sediment cores from the eight saltmarsh locations contain Foraminifera, see chapter 6.3. However, at four study sites (Loch Sligachan, Loch Ainort, Kyleakin, Loch Riddon) no calcareous species were present in the sediment cores, and only low abundances were found at three other locations (Gann, Tollesbury, Holkham). The only exception is the Two Tree Island sediment core which contains predominantly calcareous forms. A possible reason for the absence or low abundance could be explained through taphonomic processes (Haslett, 2000). Dissolution might be the most likely reason (Bradshaw, 1968; Phleger, 1970; Scott & Medioli, 1980; Edwards & Horton, 2000), because the pH in saltmarshes varies on the surface between 8.2 and 6.8 (Bradshaw, 1961). Measurements from sediment cores from Tollesbury show a mean pH of 6.7. Therefore, it could be assumed that the calcareous shells were dissolved within the sediment given enough time.

An experiment was therefore devised to test the hypothesis that calcareous Foraminifera tests dissolve in water with low pH. The aim was to use saltmarsh sediment water as a natural acidic solution and try to dissolve at least four different common saltmarsh Foraminifera species in it. However, to measure the amount of dissolved calcium carbonate ($CaCO_3$) in the water, the total alkalinity was used instead of the pH only. This is due to the fact that "alkalinity is an expression of the capacity of sea water to dissolve calcium carbonate [...] (and it is expressed) as a function of the concentration of CO_2 in water" (Haq & Boersma, 1978). Hence, it is a clear indicator of how much $CaCO_3$ would have been dissolved and can be measured with the technique of acidic titration (Talling, 1973). As a control, Atlantic seawater was used, because it has a constant total alkalinity of 2.1 and a pH of 7.8. Furthermore, the tests of the Foraminifera after the experiment could be analysed for traces of surface dissolution.

Besides Foraminifera, diatoms (brown algae) are also present on the marsh surface and when dead, they preserve in the sediment (Brasier, 1970; Bignot, 1985; Haslett, 2000). Therefore, they can be used as an alternative to calcareous microfossils due to their robust silicate shells. Furthermore, diatoms show a correlation with different saltmarsh zones like other micro-organisms, which are used in sea-level studies (Zong & Horton, 1999; Plater et al., 2000; Horton et al., 2006; Kemp et al., 2009). Therefore, an attempt is made to analyse the saltmarsh sediment cores from this study for the possible presence of diatoms, including any visible changes in their assemblage with depth.

8.2. Methods

In this part, the methods that were used for the dissolution experiment are described. For this experiment water had to be collected as well as Foraminifera tests. Then, the total alkalinity and pH of the water was measured and the tests of the Foraminifera used for SEM images. Also, observations about diatoms were made. Therefore, the saltmarsh sediment core samples from different study sites were used to prepare glass slides for the diatom analysis with a light microscope.

8.2.1. Dissolution experiment

The idea was to use saltmarsh Foraminifera of different shell types (agglutinated and calcareous) and let them dissolve in a saltmarsh and a control water with a known total alkalinity. Then, after a set amount of time (total of 6 months), the water was measured for the total alkalinity and pH. Also, from the Foraminifera tests, SEM images were made to detect any traces of dissolution on the test surface.

Experiment set-up

1.) It was decided to use pore-water from a saltmarsh. The reason behind this was that when the Foraminifera are buried when they die, the pore-water would eventually dissolve the tests. The saltmarsh water was collected from the marsh near Tollesbury in 2013. By using a goauge auger, holes of 1 m depth and 3 cm diameter were made in the high marsh area which filled with water over time. This water was extracted with a flexible rubber water hose and stored in a cleaned plastic can. In the laboratory, the water was filtered and stored in a cold room at 10°C. This water was then used for the experiment, as core water (CW). Also, a standard water had to be used as a control, which could then be compared with the marsh water. As control water, a filtered natural open-ocean seawater with a 35‰salinity from OSIL was used. This Atlantic seawater (ASW) had a constant total alkalinity of 2.1 and pH of 7.8.

2.) Different Foraminifera species were picked, and because *Ammonia* was often used in other experiments (Bradshaw, 1961; le Cadre et al., 2003) and it is found in saltmarshes, *Ammonia* spp. was one of the species used for the experiment. Also, the calcareous Foraminifera *Elphidium* spp. as well as two agglutinated forms, *Trochammina inflata* and *Jadammina macrescens*, were picked. The saltmarsh surface samples from the Isle of Wight were used for this, since only the Ostracoda were picked for a study from them (chapter 6.4). Furthermore, the Foraminifera were already dead, meaning that no rebuilding of their tests would be possible during the experiment.

3.) Glass tubes had to be prepared in which the Foraminifera with the water would be placed in for the experiment. Each of them were acid washed with 10% HCl and then rinsed with distilled water six times, then this process was repeated two more times.

4.) For the experiment, it was calculated that in one glass tube, 10 specimens of one species each were placed in 1 g of core water (CW). Also, 10 tests of *Ammonia* spp. were placed in 1 g control (ASW) water, and one glass tube was filled only with 1g of CW and ASW water each. Three replicates of each were made, and repeated for an additional three times, so that in total 84 glass tubes, 21 for four months, were prepared, see figure 8.1. Then, the glass tubes were placed in a cold room (approximately 10°C) for the duration of the experiment.

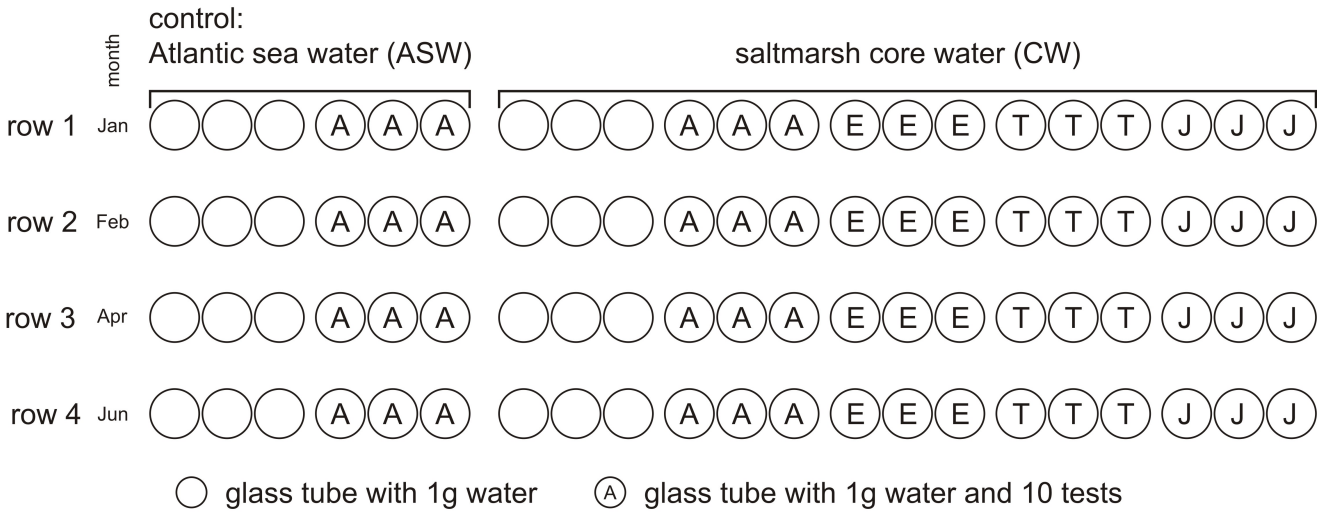


Figure 8.1.: Experiment set-up where Atlantic sea water (ASW) as standard and core water (CW) extracted from Tollesbury saltmarsh is tested on how different Foraminifera species (A = *Ammonia* spp., E = *Elphidium* spp., T = *T. inflata*, J = *J. macrescens*) in 1 g water dissolve. Every month water was replaced and then every two month, the water of each glass tube is used to measure the pH and the total alkalinity (acid titration) as well as microscopy estimates the dissolution on the Foraminifera tests.

Separately, 10 specimens of *Ammonia* spp., *Elpidium* spp. and *T. inflata* were placed each in a glass tube with 1 g core water (CW), as well as three water sample only each (ASW and CW), were produced as supplementary samples. It was planned to let these samples rest (no water changing) and to measure the total alkalinity and pH of the water after the experiment ended.

Experiment

For the experiment, the filled glass tubes were left to rest in a cold room for four month, starting in December 2013. From this time, only the total alkalinity of the water (ASW and CW) only was measured. After the first month (January 2014), from each glass tube of row 1 (figure 8.1) the Foraminifera tests were removed. Then, the total alkalinity and pH of each 1 g water per glass tube was measured, see chapter 8.2.1. Also, the water in the

remaining three rows was replaced with new one, which should simulate the water flow in the sediment. The next month (February 2014) was repeated the same way, meaning the water of row 2 was measured and the one from the remaining tubes replaced. For the third month (March 2014) however, the Foraminifera tests (from row 3) showed no traces of dissolution under a light microscope. Therefore, the time interval was increased to two month between measurements, but the water in the tubes was still replaced with new one. In the last month (April 2014), the water was measured again, but due to hardly any measured increase in total alkalinity compared to the last measurements, the water for the last row (4) was not replaced again. The experiment with the last measurements of row 4 ended in June 2014.

Furthermore, one month later (July 2014), the additional tests in the four glass of the tubes (supplementary samples) were extracted and the water measured as before. And since the results for the water only measurements of the experiment could not be used as reference lines, the stored water (CW and ASW) was measured separately twice in August 2014.

The removed Foraminifera tests were left to air dry and then one specimen from each species per month was used for SEM imaging, see chapter 2.4.

Total alkalinity and pH measurements

The first measurement of each water sample was the pH with an ORION pH meter model 420 A+. Then, the total alkalinity (mEq / kg) was measured with the technique of acidic titration (Talling, 1973), which measures the dissolved calcium carbonate ($CaCO_3$) in the water (Chisholm & Gattuso, 1991). For each measurement, a magnetic follower was placed into the glass tube which was put on a IKA topolino mini magnetic stirrer, and the pH meter remained in the water. Then, an electronic pipette (Rainin EDP Electronic Pipette 2500) was placed above the glass tube opening and an acid (0.01 M HCl) added via titration. 5 ml was titrated each time (from 2000 ml) were added, until a pH between 4.4 to 3.7 was reached. Then, the pH as well as the amount (ml) of added acid was recorded, then for four times, 15 ml of acid was titrated into the water. The measured pH and ml of acid values were inserted into the programme CO2sys (Pierrot et al., 2006) which calculated the total alkalinity (mEq / kg) of the water.

8.2.2. Diatom samples

The method to prepare the sediment for diatom analysis (Brasier, 1970; Bignot, 1985) is the same as the one used for the sediment core sample preparation for the PSA (chapter 2.5). Therefore, the remaining sediment from the processed PSA samples could be reused. From each sample, five drops of the suspended sediment was pipetted onto a glass slide and left to air dry. This process was repeated, so that from each sediment sample two slides were made. Then, with a light microscope these slides were analysed for diatoms. Eight saltmarsh sediment cores

were used for PSA, therefore, the same ones were used here: c II and TC (Tollesbury), T 3 and T 4 (Gann), c I to c III (Loch Riddon) and NNC 17 (Holkham).

8.3. Results

This experiment led to the production of two types of results. The first results include the chemical data about the total alkalinity and pH of the measured water (ASW and CW) with and without Foraminifera tests. The second type of results, are the observations on the Foraminifera tests used in the experiment from which SEM images were made. The second observation focused on diatoms and to examine if any of them would be present in the sediment of the saltmarsh cores.

8.3.1. Total alkalinity

The measured total alkalinity values in mEq / kg for all 84 samples, including the additional water and supplementary samples measurements, can be found in table I.1. The values of the original waters (ASW and CW) serve as reference lines to compare all other total alkalinity measurements to them, they were measured before (December 2013) and after the experiment (August 2014). The total alkalinity of the Atlantic seawater has a mean value of 2.1 mEq / kg, and the core water has a mean value of 2.6 mEq / kg.

The majority of the water only samples that were measured at the start of the experiment (January 2014) with a total alkalinity difference of 0.5 mEq / kg below both ASW and CW reference lines (figure 8.2). CW 3 represents an outlier as well as CW 1 with 1.1 mEq / kg difference below CW refernce line. And ASW 1 lies 0.1 mEq / kg below the ASW reference line. Then, the second values (February 2014) of total alkalinity are similar to both reference lines (ASW and CW). For CW 1 no measurement exists due to an accidental spillage. Slightly higher values (0.1 to 0.3 mEq / kg increase) are measured for the fourth month (April 2014). And these values of total alkalinity nearly stay the same (some decrease with 0.1 - 0.2 mEq / kg) for the last measurements (July 2014) from the experiment. The supplementary samples (August 2014) show similar total alkalinity values than the ones from the last month of the experiment, with around 0.1 mEq / kg increase.

The samples with calcareous Foraminifera species show similar results than the water only samples, see figure 8.3. The first total alkalinity measurements (January 2014) for *Ammonia* spp. in Atlantic seawater show 0.5 mEq / kg (ASW Am 1 and ASW Am 2) to 1 mEq / kg (ASW Am 3) values lower than to the ASW reference line. The core water with *Elphidium* spp. has 0.5 mEq / kg (CW Elph 3), 0.3 mEq / kg (CW Elph 2) and 0.1 mEq / kg (CW Elph 1) lower total alkalinity values compared to the CW reference line. For the *Ammonia* spp., CW Am 1 is 0.2 mEq / kg, CW Am 2 is 0.8 mEq / kg and CW Am 3 is 0.1 mEq / kg values of total alkalinity are below the CW reference line. The second measurements (February 2014) lie very close to both reference lines. Especially for all core water samples with *Ammonia* spp. and *Elphidium* spp., the values mostly show a slight

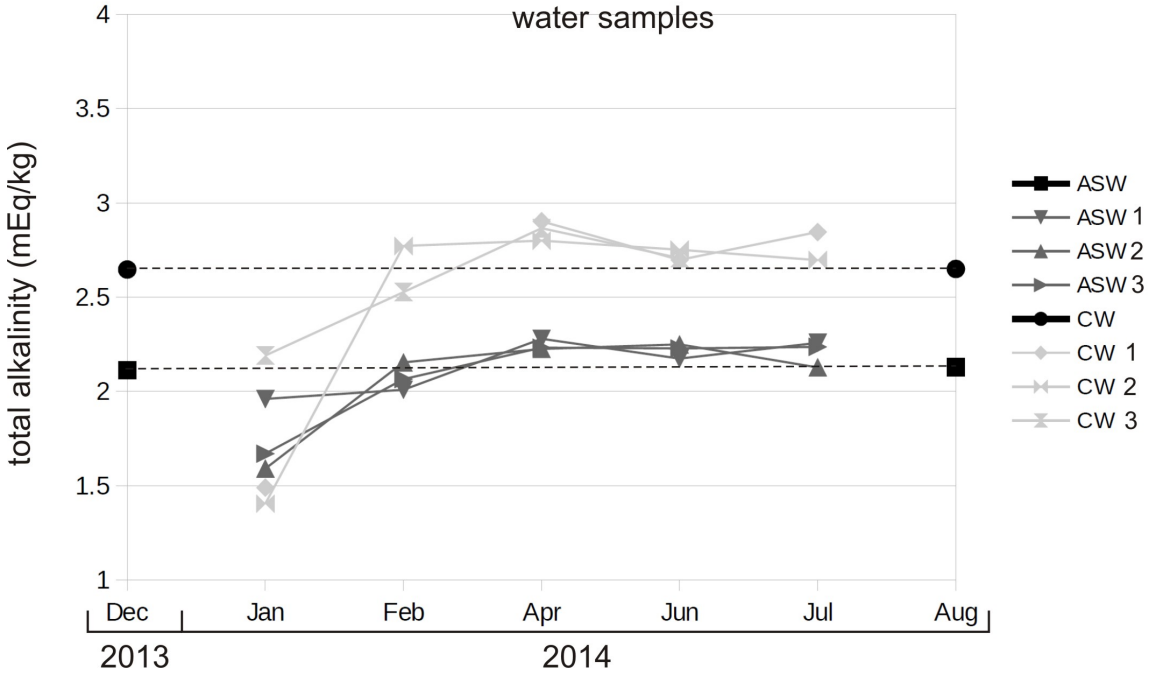


Figure 8.2.: Total alkalinity of the water only samples (3 samples with different symbols, but same colour) shown for the 6 month experiment (January to June 2014) and the water samples (December 2013 and August 2014) as reference (black dotted) lines, as well as the supplementary samples (July 2014), ASW = Atlantic seawater, CW = core water ASW 1-3 and CW 1-3 = experiment samples.

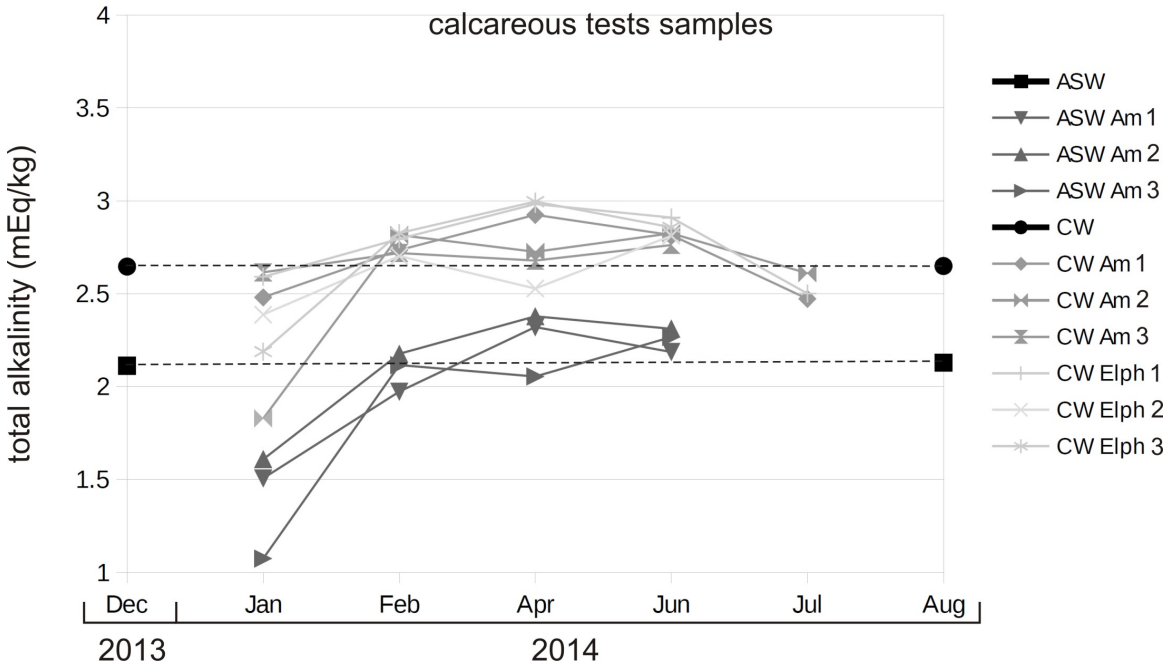


Figure 8.3.: Total alkalinity of the water samples with calcareous Foraminifera (3 samples with different symbols, but same colour) shown for the 6 month experiment (January to June 2014) and the water samples (December 2013 and August 2014) as reference (black dotted) lines, as well as the supplementary samples (July 2014), ASW = Atlantic seawater, CW = core water, CW Am 1-3 = core water with *Ammonia* spp., CW Elph 1-3 = core water with *Elphidium* spp..

increase of 0.1 - 0.2 mEq / kg. The Atlantic seawater with *Ammonia* spp. samples show the same total alkalinity values for ASW Am 2 and ASW Am 3 as the ASW reference line, only ASW Am 1 is 0.2 mEq / kg lower. The values for total alkalinity from the fourth month (April 2014) reveal ca. 0.2 mEq / kg increased and decreased values compared to both reference lines. ASW Am 1 and ASW Am 2 have 0.2 mEq / kg higher, and ASW Am 3 were 0.1 mEq / kg lower values compared to the ASW reference line. A similar pattern can be seen for the core water with *Elphidium* spp. samples, where CW Elph 2 shows 0.1 mEq / kg lower and for both, CW Elph 1 and CW Elph 3, show a 0.4 mEq / kg higher value compared to the CW reference line. The last measurements of the experiment (June 2014) show for all samples 0.1 mEq / kg higher values compared to both reference lines. The supplementary samples (CW Am 1, CW Am 2, CW Elph 1) show for CW Am 1 and CW Elph 1 0.1 mEq / kg lower and for CW Am 2 the same total alkalinity value than the CW reference line (July 2014).

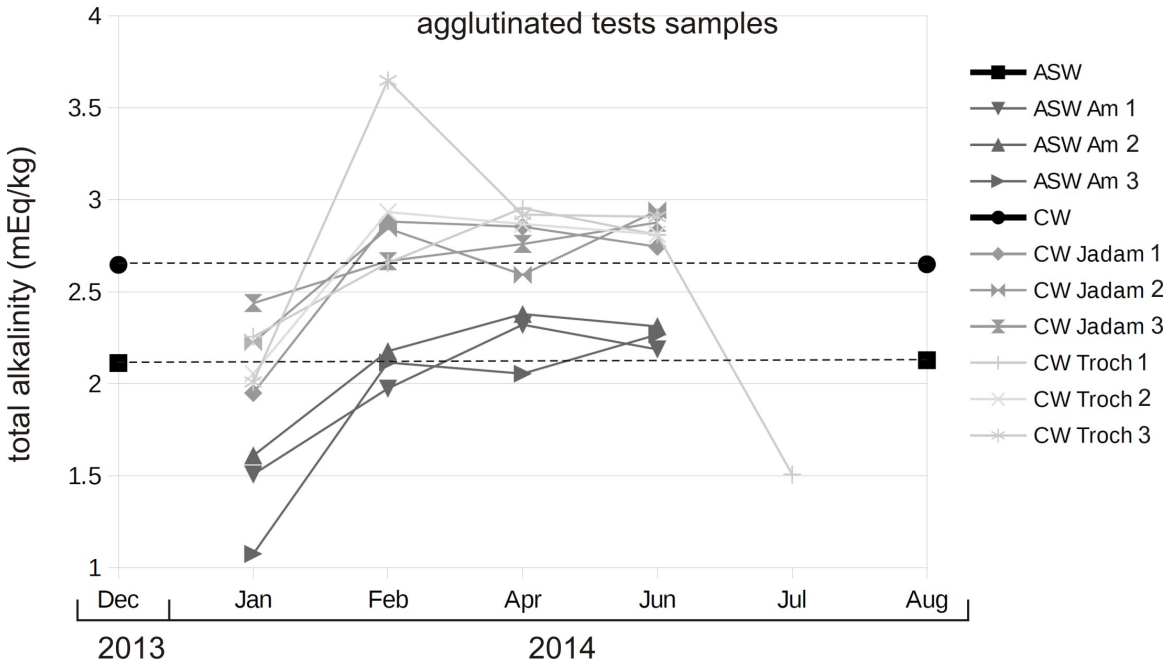


Figure 8.4.: Total alkalinity of the water samples with agglutinated Foraminifera (3 samples with different symbols, but same grey colour) shown for the 6 month experiment (January to June 2014) and the water samples (December 2013 and August 2014) as reference (black dotted) lines, as well as the supplementary samples (July 2014), ASW = Atlantic seawater, CW = core water, CW Jadm 1-3 = core water with *J. macrescens*, CW Troch 1-3 = core water with *T. inflata*.

The samples with agglutinated Foraminifera species have more 'outliers' compared to the measurements of total alkalinity from the calcareous forms. Figure 8.4 also includes the *Ammonia* spp. samples with Atlantic seawater again, which were described above, to function as another reference, besides the ASW and CW reference lines. The first measurements of the experiment (January 2014) show for all samples (*Jadammina macrescens* and *Trochammina inflata*) lower total alkalinity values compared to the CW reference line. For the *J. macrescens* in

core water, the sample CW Jadam 1 is 0.7 mEq / kg, CW Jadam 2 is 0.4 mEq / kg and CW Jadam 3 is 0.2 mEq / kg, show lower values compared to the CW reference line. The samples *T. inflata* in core water, show for CW Troch 2 and CW Troch 3 0.6 mEq / kg, and for CW Troch 1 0.4 mEq / kg lower total alkalinity values to the CW reference line. The second set of measurements (February 2014) show that CW Jadam 3 and CW Troch 1 lie on the CW reference line, but CW Jadam 1, CW Jadam 2 and CW Troch 2 have 0.2 mEq / kg increased values. The sample CW Troch 3 represents an outlier and lies with a 1 mEq / kg higher value above the CW reference line. For the fourth month (April 2014), all *T. inflata* samples show nearly the same results, showing 0.4 mEq / kg increased values compared to the CW reference line. For *J. macrescens*, the sample CW Jadam 3 lies 0.05 mEq / kg below and CW Jadam 1 and CW Jadam 2 lie 0.1 - 0.2 mEq / kg above the CW reference line. The last measurements (June 2014) from the experiment show for all samples increase total alkalinity values. Here, CW Troch 1 to CW Troch 3 show 0.2 - 0.3 mEq / kg higher values compared to the CW reference line. And the CW Jadam 1 to CW Jadam 3 show total alkalinity values that lie 0.1 mEq / kg, 0.2 mEq / kg, 0.4 mEq / kg values above the CW reference line. Only one additionally sample (CW Troch 1) was measured (July 2014) with a 1 mEq / kg value below the CW reference line, representing an outlier.

8.3.2. pH analysis

The measured pH values from the experiment for all 84 samples, including the additional water and supplementary samples measurements, can be found in table I.2. The values of the original waters (ASW and CW) serve as reference lines to compare all other pH measurements to them. They were measured before (December 2013) and after the experiment (August 2014). The pH of the Atlantic seawater (ASW) has a mean value of 7.9 (December 2013) and decreases to 7.7 (August 2014). The pH of the core water (CW) has a mean value of 7.5 (December 2013) and increases to 7.9 (August 2014). Additionally, from the sediment core (c II) at Tollesbury, a pH of 6.8 was measured in the field.

A pH of 7.3 - 7.4 was measured from most of the water only samples (figure 8.5) at the start of the experiment (January 2014). Except for the samples CW 1 and CW 3 which show a value of 6.9. The next set of samples from the second month (Februrary 2014) show pH values of 7.7 which lie on the CW reference line. Only the samples ASW 2 and ASW 3 show lower values of 7.5 and 7.4. No data for sample CW 1 is available, due to an accidental spillage. The pH measurements for the fourth month (April 2014) reveal that the values of the CW samples all scatter around 7.7 - 7.8 which lie on the crossing of both reference lines (ASW and CW). The ASW 1 and ASW 2 samples have a pH of 7.5, and the ASW 3 a pH of 7.6. For the last month (June 2014) of the experiment, the pH values of all samples show a similar pattern compared to the previous measurements, with slightly higher pH values for the CW samples (7.7 - 7.9) and lower for all ASW samples (7.6 - 7.7). From the three ASW samples, supplementary ones were made, which show the same pH values than the ones measured from the last month.

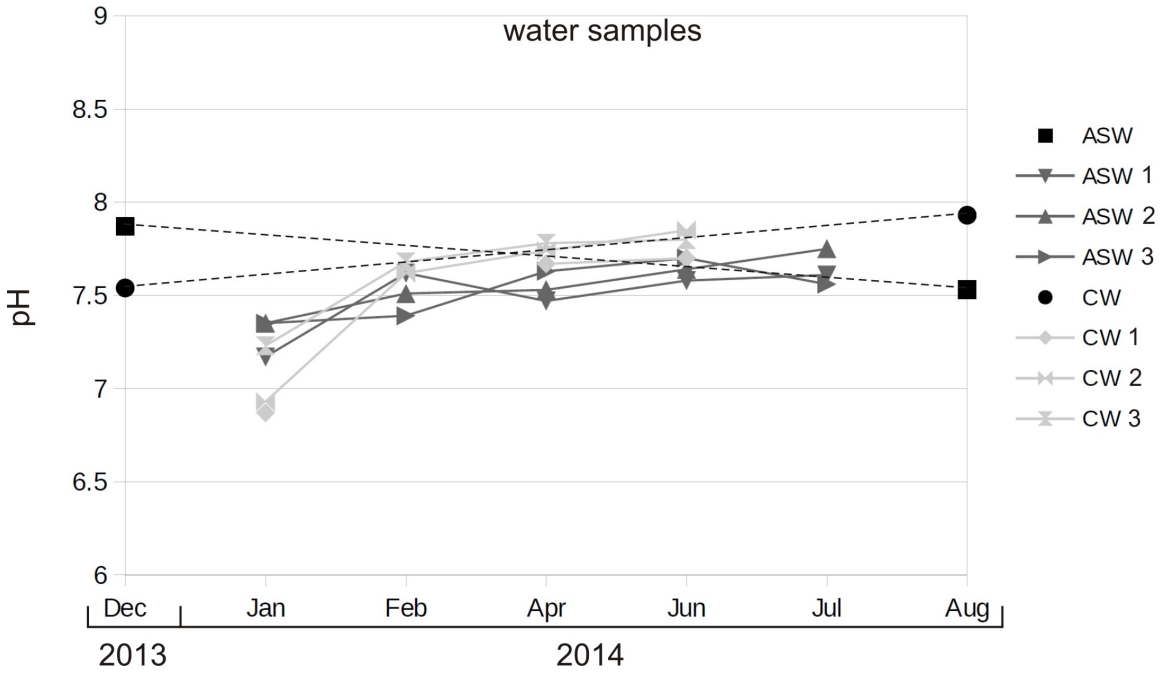


Figure 8.5.: pH measurements from the water only samples (3 samples with different symbols, but same colour) shown for the 6 month experiment (January to June 2014) and the reference water samples (December 2013 and August 2014), as well as the supplementary samples (July 2014). ASW = Atlantic seawater, CW = core water, ASW 2 and CW 2 = experiment samples.

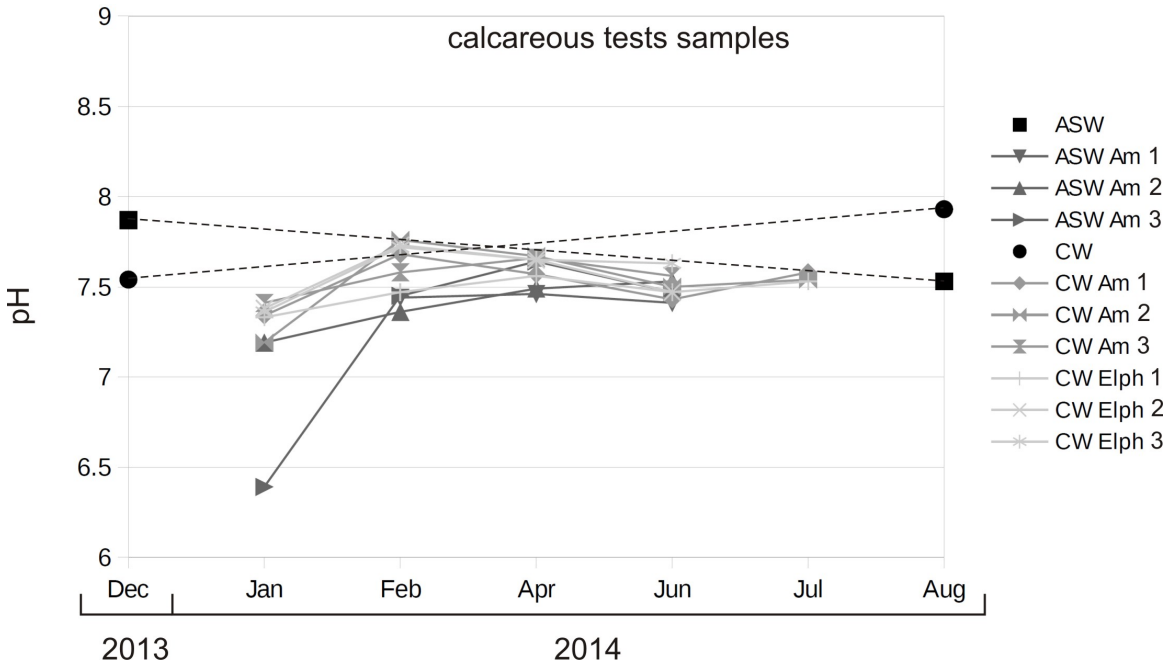


Figure 8.6.: pH measurements from the water samples with calcareous Foraminifera (3 samples with different symbols, but same colour) shown for the 6 month experiment (January to June 2014) and the reference water samples (December 2013 and August 2014), as well as the supplementary samples (July 2014). ASW = Atlantic seawater, CW = core water, CW Am = core water with *Ammonia* spp., CW Elph = core water with *Elphidium* spp..

From the first month of the experiment (January 2014), the samples with calcareous Foraminifera species (*Ammonia* spp. and *Elphidium* spp.) in core water show all nearly the same pH value of 7.4 (figure 8.6). Only CW Am 2 shows a pH of 7.3, as well as the sample ASW Am 2 with *Ammonia* spp. in Atlantic seawater do. ASW Am 3 represents an outlier with a pH value of 6.4, and no data were collected for ASW Am 1. For the second month (February 2014) the measured pH value lie all below the ASW reference line. Between both reference lines with a pH of 7.8, lie the samples CW Elph 2, CW Elph 3 and CW AM 2. CW AM 1 has a pH of 7.7 and CW AM 3 7.6. The ASW Am 1 and ASW Am 3 samples cluster around the pH value of 7.5, as well as the sample CW Elph 1. The lowest value of this month shows sample ASW Am 2 with a pH of 7.4. The all pH values of the fourth month (April 2104) cluster nearer together than before, ranging from 7.4 - 7.7. Here, all ASW Am samples show a pH value between 7.5 - 7.6, whereas the CW Am samples range from 7.6 to 7.7 pH as well as the CW Am samples. The last month of the experiment (June 2014) contain slightly lower pH values, but they still cluster around a similar value compared to the last month measurements. The highest pH value has CW Elph 3 with 7.6, whereas, CW Elph 1 and CW Elph 2 show a pH of 7.5. All other samples (ASW Am and CW Am) show a pH between 7.4 - 7.5. Three supplementary samples (CW Am 1, CW Am 2, CW Eph 1) have the same pH of 7.5 (July 2014).

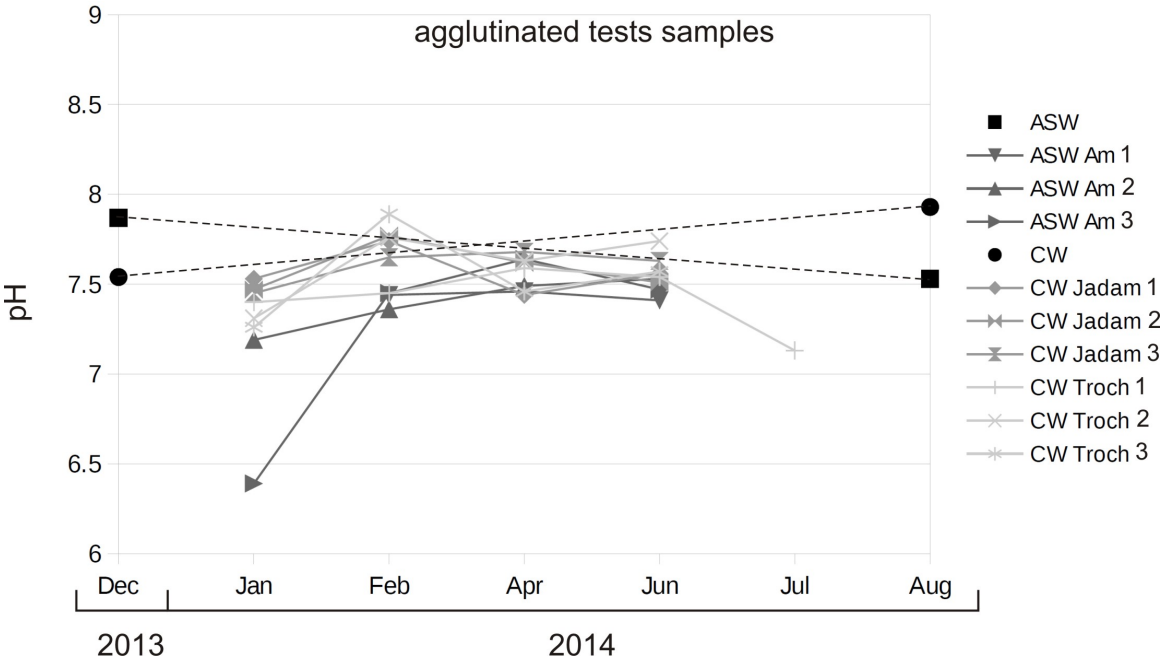


Figure 8.7.: pH measurements from the water samples with agglutinated Foraminifera (3 samples with different symbols, but same colour) shown for the 6 month experiment (January to June 2014) and the reference water samples (December 2013 and August 2014), as well as the supplementary samples (July 2014). ASW = Atlantic seawater, CW = core water, CW Jadm = core water with *J. macrescens*, CW Troch = core water with *T. inflata*.

The samples with agglutinated Foraminifera species show more variation for the pH values compared to the ones with calcareous forms. Figure 8.7 also includes the *Ammonia* spp. samples with Atlantic seawater again, which were described above, to function as another reference points, besides the ASW and CW reference lines. For the first month (January 2014), the all samples with (*Jadammina macrescens* and *Trochammina inflata*) show lower total alkalinity values compared to the CW reference line. The CW Jadm samples cluster closer together, around a pH of 7.5. Compared to them, the CW Troch samples have lower pH values, except for CW Troch 1. The other have a pH of 7.3. The second month (February 2014) pH values scatter more than the last month values, where CW Troch 3 shows the highest pH with nearly 7.9, and CW Troch 1 the lowest value with 7.4. The remaining samples (CW Troch 2 and CW Jadm) cluster around a pH of 7.7. The pH measurements of month four (April 2014) are slightly lower than the last ones, with 7.5 (CW Troch 3, CW Jadm 1) to 7.6 (CW Troch 1, CW Troch 2, CW Jadm 2, CW Jadm 3). The last pH measurements of the experiment (June 2014), are similar to the last ones, where all samples cluster around a pH between 7.5 - 7.6. The sample CW Troch 2 show a higher pH of 7.7. Only one supplementary sample (CW Troch 1) exists which shows an outlier with a pH value of 7.1 (July 2014).

8.3.3. Foraminifera observations (SEM)

After the experiment, the calcareous tests of *Ammonia* spp. from the Atlantic Sea Water from all six months showed no traces of dissolution on the test surface nor at the pores (Plate A, figure 1-4).

The calcareous species *Ammonia* spp. (Plate A, figure 5-8) and *Elphidium* spp. tests (Plate B, figure 1-4) from the sediment core water as well as all agglutinated specimens *Jadaminna macrescens* (Plate B, figure 5-8) and *Trochaminna inflata* (B, figure 9-12) showed after their extracted from the water no traces of dissolution on the test surface nor at the pores.

None of the experiments resulted in any evidence of dissolution that could be observed.

Plate A

Fig. 1-8: *Ammonia* spp.

1: umbilical view, 190x, Isle of Wight (IW north), Atlantic Sea Water (control), 22^{nd} January 2013.

2: umbilical view, 190x, Isle of Wight (IW north), Atlantic Sea Water (control), 20^{th} February 2013.

3: umbilical view, 190x, Isle of Wight (IW north), Atlantic Sea Water (control), 24^{th} April 2013.

4: umbilical view, 190x, Isle of Wight (IW north), Atlantic Sea Water (control), 20^{th} June 2013.

5: umbilical view, 190x, Isle of Wight (IW north), sediment core water, 22^{nd} January 2013.

6: umbilical view, 190x, Isle of Wight (IW north), sediment core water, 20^{th} February 2013.

7: umbilical view, 190x, Isle of Wight (IW north), sediment core water, 24^{th} April 2013.

8: umbilical view, 190x, Isle of Wight (IW north), sediment core water, 20^{th} June 2013.


Plate A
1
5
2
6
3
7
4
8
100 µm

Plate B

Fig. 1-4: *Elphidium* spp.

1: lateral view, 160x, Isle of Wight (IW north), sediment core water, 22^{nd} January 2013.

2: lateral view, 140x, Isle of Wight (IW north), sediment core water, 20^{th} February 2013.

3: lateral view, 140x, Isle of Wight (IW north), sediment core water, 24^{th} April 2013.

4: lateral view, 160x, Isle of Wight (IW north), sediment core water, 20^{th} June 2013.

Fig. 5-8: *Jadammina macrescens*

5: spiral view, 160x, Isle of Wight (IW north), sediment core water, 22^{nd} January 2013.

6: spiral view, 160x, Isle of Wight (IW north), sediment core water, 20^{th} February 2013.

7: umbilical view, 160x, Isle of Wight (IW north), sediment core water, 24^{th} April 2013.

8: spiral view, 190x, Isle of Wight (IW north), sediment core water, 20^{th} June 2013.

Fig. 9-12: *Trochammina inflata*

9: umbilical view, 160x, Isle of Wight (IW north), sediment core water, 22^{nd} January 2013.

10: umbilical view, 130x, Isle of Wight (IW north), sediment core water, 20^{th} February 2013.

11: umbilical view, 160x, Isle of Wight (IW north), sediment core water, 24^{th} April 2013.

12: umbilical view, 160x, Isle of Wight (IW north), sediment core water, 20^{th} June 2013.

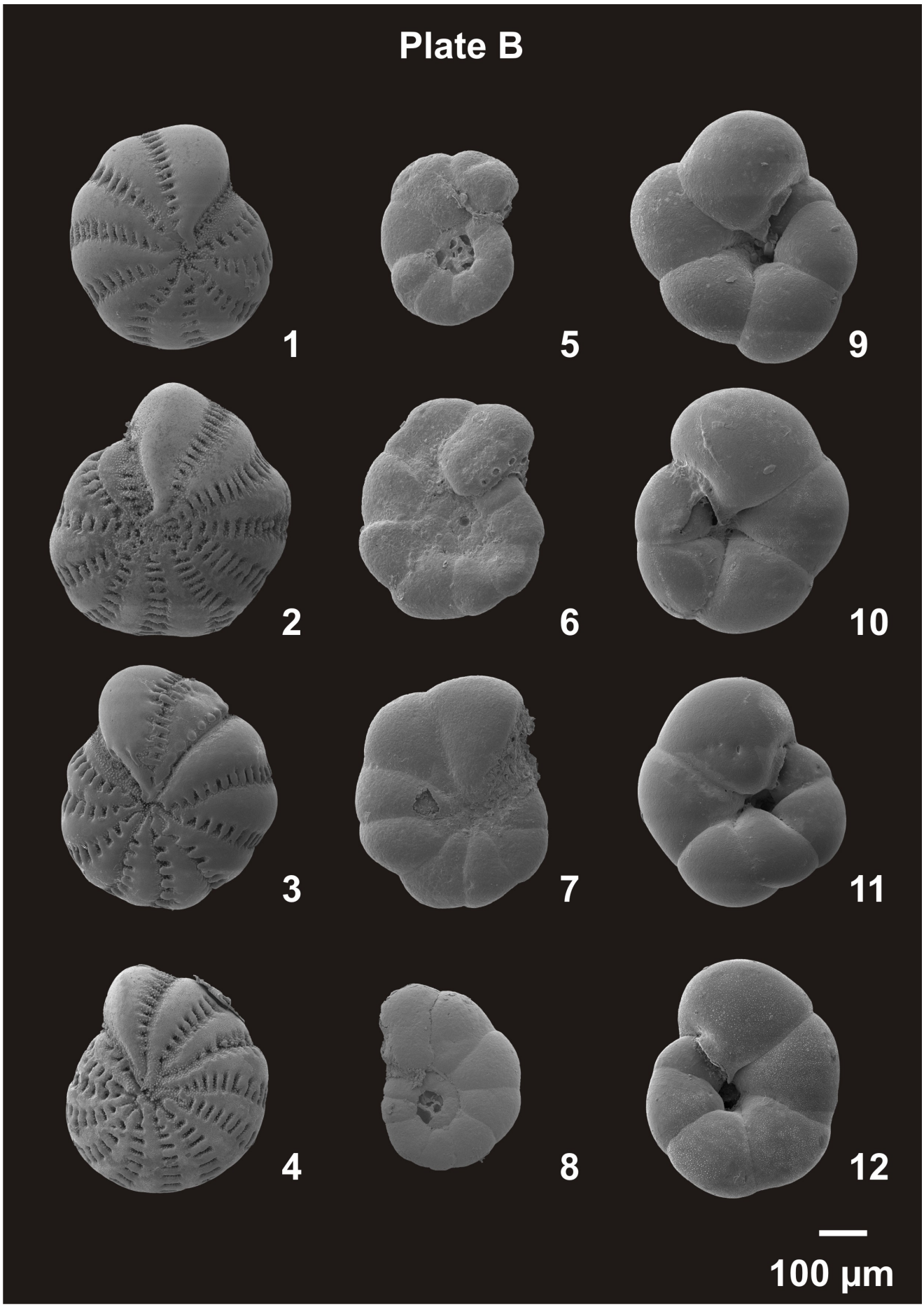


Plate B
1
5
9
2
6
10
3
7
11
4
8
12
100 µm

8.3.4. Diatom observations

From the Tollesbury study site, two sediment cores were used for PSA, the high marsh core c II and mid marsh core TC. The first core (c II) is 4 m long and was divided into 40 samples. The analysed glass slides from all samples contain no diatoms. The second core is 5 m long, but only 17 samples (every third) were processed for PSA. It was observed that in the top 1 m of the core (TC 1 to TC 10), the diatoms are bigger than the ones in the remaining samples which also show a higher diversity. And towards the bottom of the core the abundance also decreases as well, so that the lowest two samples contain hardly any diatoms.

In the two sediment cores from Gann (T 3 and T 4) from the mid and low marsh, with each of approximately 1 m length, diatoms were found in all core samples. Their size nor their diversity change,. However, the samples contain more diatoms per sample than the TC core from Tollesbury.

In all Loch Riddon saltmarsh cores no diatoms were observed, and hardly any were found in the NNC 17 from Holkham.

All observed diatoms had bipolar siliceous frustule (pennales). No round forms (centrales) were found.

8.4. Discussion of the experiment results and meiofauna observations

Here, the measured total alkalinity and pH values are discussed and interpreted, as well as the observations on Foraminifera tests. Also, the diatom data are analysed and compared with the results from the dissolution experiment.

8.4.1. Total alkalinity and pH measurements

The following discussion of the alkalinity and pH results left out the measured outlier. For the alkalinity, the sample (CW Troch 3) with *T. inflata* as well as the supplementary sample (CW Troch) with *T. inflata* have been ignored. For the pH, sample ASW Am 3 (January 2014) and the supplementary sample CW Troch have been left out.

Figure 8.8 and 8.9 show the mean values of the total alkalinity (mEq / kg) per month and calcareous (ASW Am, CW Am, CW Elph) / agglutinated (CW Jadam, CW Troch) tests or water only (ASW 1 and CW 1) samples. Also two reference lines exist (from December 2013 to August 204) for the Atltanic seawater (ASW) and core water (CW) which show the the total alkalinity measured before and after the experiment of the stored water. These values hardly change, only an increase of 0.05 mEq / kg for both over eight months was detected, which might be due to storing, since the ASW should have a constant alkalinity value of 2.1 mEq / kg. Still they can be used as reference lines, and it was also attempted to use the measured water samples (ASW 1 and CW 1) from the experiment as reference lines as well. However, ASW 1 shows a decrease of 0.3 mEq / kg and CW 1 decreases

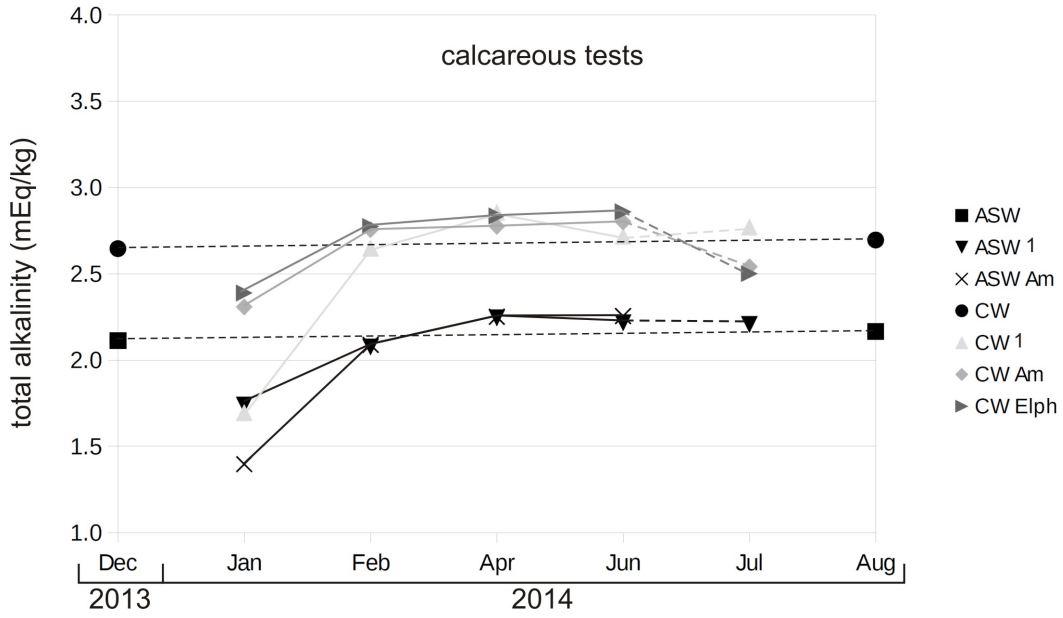


Figure 8.8.: The graph is showing the mean of the measured total alkalinity (mEq / kg) per month and calcareous species or water sample (ASW=Atlantic seawater, CW=core water, ASW Am=*Ammonia* spp. in Atlantic seawater, CW Am=*Ammonia* spp. in core water, CW Elph=*Elphidium* spp. in core water). The lines represent the measurements from the experiment, the dotted lines the supplementary samples. Also, two reference lines for ASW and CW are shown (black dotted line).

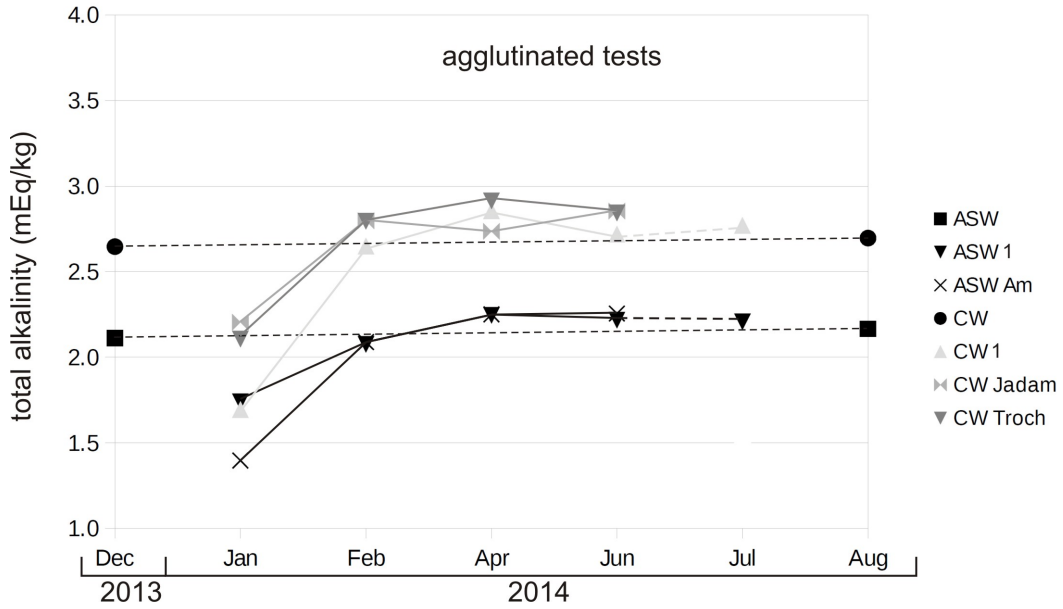


Figure 8.9.: The graph is showing the mean of the measured total alkalinity (mEq / kg) per month and agglutinated species or water (ASW=Atlantic seawater, CW=core water, ASW Am=*Ammonia* spp. in Atlantic seawater, CW Jadam=*J. macrescens* in core water, CW Troch=*T. inflata* in core water). The lines represent the measurements from the experiment, the dotted lines the supplementary samples. Also, two reference lines for ASW and CW are shown (black dotted line).

to 0.9 mEq / kg for the first measurements of the experiment (January 2014) compared to both reference lines. These alkalinity values form the samples with the Foraminifera species also show this decreasing trend for the first measurements. This lowered values for all samples could be explained due to a contamination, because the water only samples (ASW 1 and CW 1) also show this pattern. The contamination probably occurred during the preparation of the glass tubes, even if the tubes were acid washed. The alkalinity values for the agglutinated tests compared to the calcareous ones show lower values. This difference might be due to the ability to resit acidic solutions differently for different species, as shown in other experiments (Bradshaw, 1961), because of their difference wall compositions.

However, this is not true for the next measurements from the second month (February 2014), where all CW Foraminifera samples show an alkalinity increase up to 2.7 mEq / kg. And this time, no differences between the species (calcareous or agglutinated) can be seen. The same increasing trend of alkalinity can also be detected for the ASW Am sample. Where it shows a decreased alkalinity value in the first month, like the other samples, it shows the same value than ASW 1 in the second month. Moreover, from here on until the end of the experiment, there is no noteworthy difference between the measured alkalinity of ASW with (ASW Am) and without *Ammonia* spp. (ASW 1). This can be interpreted that no dissolution of *Ammonia* spp. occurred, since the ASW 1 values are the same. Otherwise, the CW samples with Foraminifera do show a solution of their tests, because the CW 1 water samples often show lower alkalinity values, except for April 2014. The following alkalinity values from all samples in the fourth month (April 2014), show a slowed down increasing trend with only ca. 0.2 mEq / kg instead of 0.4 mEq / kg from January, even though the water was changed up until now. This probably means that whatever the contamination caused in the first month, starts to stop influencing the samples, because the alkalinity values of all samples show hardly any changes until the end of the experiment (June 2014). For the last month, the alkalinity values from the Foraminifera samples indicate a slight solution, because these samples show an increased value compared to the CW samples.

The supplementary samples (July 2014) with tests which were let to rest during the experimental time, show a difference of 0.2 mEq / kg for CW Am and 0.1 mEq / kg for CW Elph compared to ones from the first month (January). The water only samples (ASW 1 and CW 1) continue its trend from the previous two months, but also show an increased alkalinity values compared with the initial samples. However, comparing them to both reference lines, CW 1 as well as ASW 1 have 0.1 mEq / kg higher values. This might also be due to the initial contamination, because the CW Am and CW Elph samples also show similar alkalinity values than the ones from January, meaning that the contamination affected those samples as well. However, all samples (with tests and without), except the ones from January, show values above their respectively reference line or close to it (for February). This increase could be due to the changing water for the first two months of the experiment, which seems to have buffered the effect of the contamination by raising all values above the reference lines. Only the

supplementary samples with tests did not, because no water was changed, and no dissolution occurred. For the samples from the experiment, the Foraminifera experienced slight solutions, as described above. However, if these Foraminifera would be in the sediment, they would have dissolved at a very slow rate, if at all, which means that the measurements of the total alkalinity do not support the hypothesis.

The pH measurements compared to the total alkalinity values, show less variance between the samples with calcareous and agglutinated tests, as well as CW and ASW water samples, see figure 8.10 and 8.11. Also the values for the pH reference lines, for ASW and CW, are not as stable (chapter 8.3.2), like the ones from the alkalinity. So when even the pH of the stored water changed outside of the experiment, then the pH values from the experiment have to be perceived with great care. However, the overall trend of the measured pH from the samples, show a similar pattern like the measured total alkalinity values. There as well as here, all samples (Foraminifera and water) from the first month (January 2014) show the lowest measured values from the experiment, reaching from 6.7 - 7.4. Then, the pH from the second month (February 2014) show increased values, ranging between 7.4 - 7.7. For the last two measurements (April and June 2014) the pH remains mostly in this interval, but show a slight decreasing trend towards the end of the experiment. And the supplementary samples (July 2014) show pH values between 7.5 - 7.6, which is similar compared to the last three measurements from the experiment.

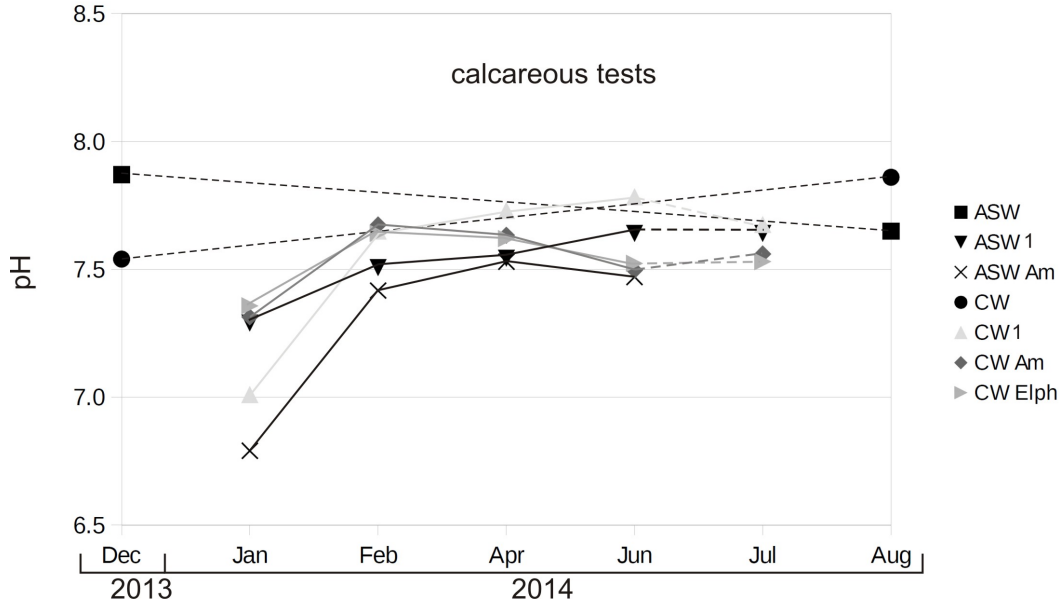


Figure 8.10.: The graph is showing the mean of the measured pH per month and calcareous species or water sample (ASW=Atlantic seawater, CW=core water, ASW Am=*Ammonia* spp. in Atlantic seawater, CW Am=*Ammonia* spp. in core water, CW Elph=*Elphidium* spp. in core water). The lines represent the measurements from the experiment, the dotted line the supplementary samples. Also, two reference lines for ASW and CW are shown (black dotted line).

When focusing on the different pH values measured for the samples with calcareous and agglutinated tests, the latter one show slightly higher values for the first two months, compared to the samples with calcareous forms. Then for the fourth month (April 2014) the pH is lower, but for the last month (June 2014) of the experiment, the measured pH is nearly the same than the one form the calcareous tests samples. And comparing the core water (CW 1) sample to all CW samples with tests, the pH values for the first two month is lower, but higher for the last two months (April, June). This could mean that the lower pH first reflect a more acidic water, but over time, the water (with tests) becomes less acidic due to the solution of the Foraminifera. Given that in other experiments the pH of 7.8 (Bradshaw, 1961) and 7.5 (le Cadre et al., 2003) were seen as values where solution of the tests begins, the pH from the first two months (between 6.7 - 7.7) of the experiment would fit. However, since the core water sample alone show a low pH which increases in time, nothing could have been dissolved in it to lower the pH. Therefore, it can be concluded that possible contamination (probably during glass tube preparation) occurred, which was buffered through changing waters in the first two months and stopped in the fourth month. And the pH data for April and June (and July) indicate no solution of the Foraminifera. This is because the pH values of each water sample (ASW 1 and CW 1) is always higher than the respectively ones with tests. Meaning that, if solution would occur, the samples with tests would have higher pH values due to the solution of $CaCO_3$ than the plain water samples which they have not. These measured pH values, which do not show a solution of the Foraminifera tests in saltmarsh pore-sediment water, do not support the hypothesis as proposed.

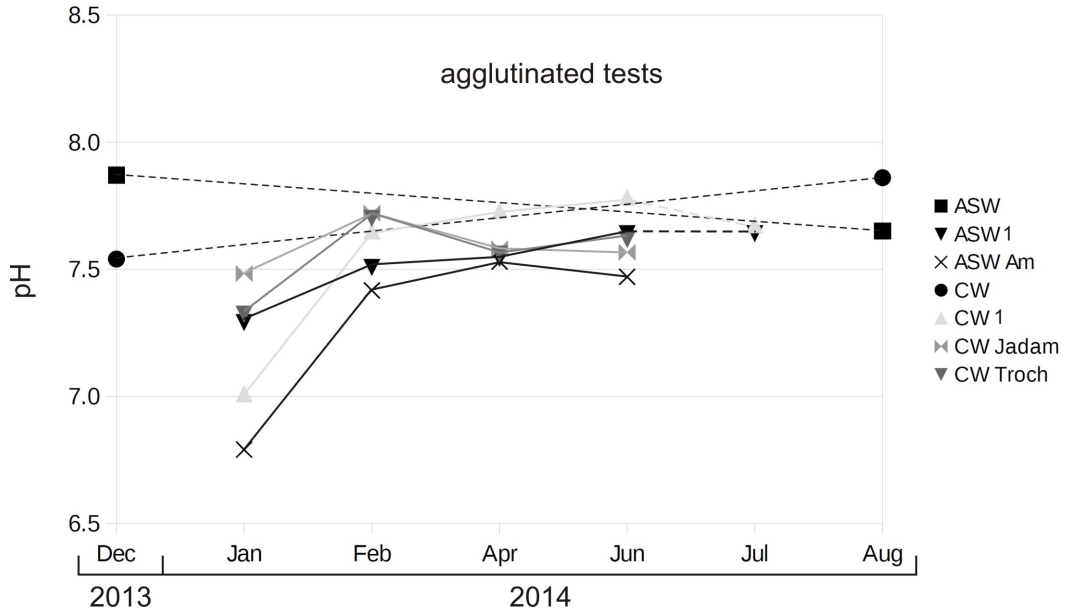


Figure 8.11.: The graph is showing the mean of the measured pH per month and agglutinated species or water sample (ASW=Atlantic seawater, CW=core water, ASW Am=*Ammonia* spp. in Atlantic seawater, CW Jadam=*J. macrescens* in core water, CW Troch=*T. inflata* in core water). The lines represent the measurements from the experiment, the dotted line the supplementary sample. Also, two reference lines for ASW and CW are shown (black dotted line).

8.4.2. Foraminifera and diatom observations

All Foraminifera tests, calcareous and agglutinated, from the dissolution experiment show no traces of dissolution on their surfaces after the experiment. Therefore, it can be assumed that no dissolution occurred, which would fit with the total alkalinity results, meaning that the proposed hypothesis is not supported.

As for the diatom observations from the glass slides, all core samples from the northern study site at Loch Riddon, contain no diatoms. This absence cannot be explained, since diatoms normally occur in saltmarshes on sandy and muddy substrates equally (de Seve et al., 2013), with Loch Riddon having a sand dominating environment (chapter 6.3.4). Also, in sea-level studies it is assumed that "the distribution of saltmarsh diatoms is a direct function of elevation, with the most important controlling factors being the duration and frequency of subaerial exposure" (Horton et al., 2006). And thus, diatoms occur in low to high marsh zones (Zong & Horton, 1999; Espinosa et al., 2006; Kemp et al., 2009). However, one of the Tollesbury sediment cores (c II from the high marsh) also contains no diatoms, in all samples, but the core from the outer marsh (TC) does. This could be due to the environmental stress as it is found to increase from low to high marsh (Long & Mason, 1983). And observations from saltmarshes indicate that diatoms most likely live predominantly around creeks, because their brown patches of colonies can only be seen there. If so, then the c II core would reflect only high marsh conditions throughout (chapter 6.3.1), compared to the high-mid marsh core TC. There, changes in diversity would indicate a change of the marsh zones within the core. This could be correlated with the occurrence of calcareous Foraminifera at a depth of 1.9 m and downwards (chapter 6.3.1). In all Gann saltmarsh cores (T 3 and T 4, from high-mid and low marsh) diatoms were found as well, but show no changes in diversity. This would fit with the presence of calcareous Foraminifera in all core samples of both cores (chapter 6.3.3) which also seem to show no clear trend. Moreover, the NNC 17 core from Holkham shows a low abundance of diatoms in the core samples as well as a low abundance of Foraminifera (chapter 6.3.8). No diatoms were found in the last sample, which reflects a high marsh indicated by the agglutinated Foraminifera. The calcareous species appear in the middle part of the core (between 2 m and 7 m depth), where diatoms were found. This correlation between diatoms and calcareous Foraminifera could mean that diatoms might have the same preference to environmental (living) conditions. If so, then the absence of diatoms in the Loch Riddon cores could be explained, because no calcareous Foraminifera occur there as well.

It can be argued that a possible pollution affected the diatoms at Loch Riddon, but pollution would change the diatom diversity (de Seve et al., 2013) and not explain the lack of diatoms. Furthermore, at the Neston marsh no planktonic diatoms appear, only as fragments, "probably due to the grinding action of sand particles during tidal ebb and flow" (Round, 1960). This could be a possible explanation for the missing diatoms, because the saltmarsh at Neston, Cheshire (north-west Wales) (Round, 1960) also has a sandy environment. However, the sediment

from the c II Tollesbury core contains a clay rich silt throughout, and hardly any sand, so the absence of diatoms might not be connected to grinding particles there. However, because only observations were made and no actual diatoms counted (too time consuming), they could have been overlooked. Also because brackish and marine forms are very small compared to freshwater forms (Bignot, 1985). Therefore, like calcareous Foraminifera, the environmental condictions did not allow for diatoms to live, and found, in the sediment cores from the high marsh. This means that the hypothesis is not supported.

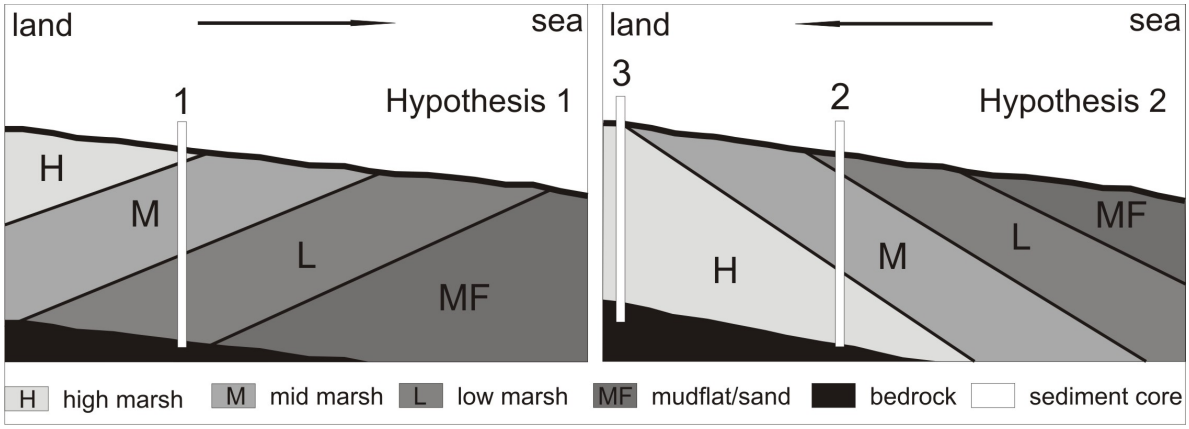
9. Conclusion

Saltmarshes are thought to form through facilitation succession, where a marsh develops from low to high marsh (Hypothesis 1). In this study, a competing hypothesis (Hypothesis 2) is tested, where under relative SLR saltmarshes develop from high to low marsh instead (figure 9.1a). It was predicted that saltmarshes supporting hypothesis 2 would be found in the areas with a relative sea-level rise (south UK), due to the isostatic rebound of the land after the LGM with its ice loss. In contrast, hypothesis 1 would be true for marsh development where a relative sea-level drop occurred (north UK). To test both hypotheses, sediment cores from eight UK saltmarshes were analysed to reconstruct its development. Therefore, Foraminifera and Ostracoda assemblages from surface samples were planed to use as marsh zone indicators, because of their known shell preservation.

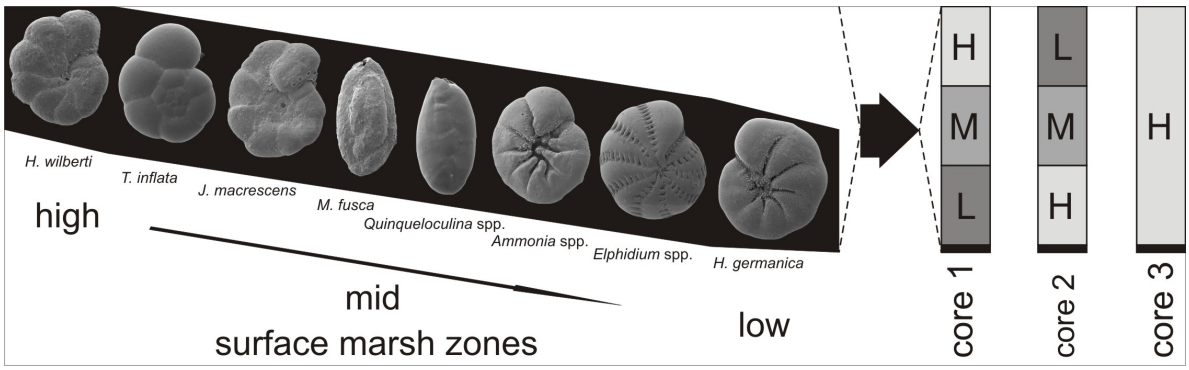
In order to extract the Foraminifera and Ostracoda from the samples, a new extraction method was developed and used to separate the sediment from the plant remains, because they tend to agglutinated together when dried. During this extraction, each sample was split in two, with the sediment sub-sample (II) containing the highest abundance of Ostracoda, whereas, the plant remains sub-sample (I) mostly trapped the smaller specimens that would have been lost due to the bigger sieve size of 125 µm. Furthermore, the sub-sample weight differences did not hinder this finding, because for both sub-samples the same amount of picking trays (three to four) was looked trough. It was also found that Foraminifera in a core sample would show the same distribution as Ostracoda in the surface sub-samples, when applying the extraction method. As a result, this method was used for all — surface and core — samples in this study, where sub-sample II was sorted though only. Except, when hardly any micro-organisms were found, sub-sample I was also used.

The surface samples collected from each saltmarsh zone per study site showed for Foraminifera a clear species and assemblage distribution per marsh zone (high, mid, low), see figure 9.1b. However, due to the higher species diversity in the southern study sites (Holkham, Tollesbury, Two Tree Island, Gann) the Foraminiferal assemblages per marsh zone show variations to the ones collected from the remaining studied saltmarshes further north. The southern Foraminiferal assemblages showed high abundances of *Trochammina inflata* and *Jadammina macrescens* for the high marsh, *Miliammina fusca* and *Quinqueloculina* spp. for the mid marsh, and *Ammonia* spp., *Elphidium* spp. and *Haynesina germanica* for the low marsh zone. In the northern saltmarshes, the Foraminiferal assemblages showed high abundances of *Haplophragmoides wilberti* and *T. inflata* for the high marsh, *J. macrescens* for

the mid marsh and *M. fusca* with *Elphidium* spp. for the low marsh zones. As a rule, agglutinated species tended to be most common at high and mid marsh, whereas calcareous forms tended to be dominating the low marsh area as well as mudflat. Similar distribution patterns between agglutinated and calcareous species are already known from other saltmarshes and used in sea-level studies. This distinct Foraminiferal distribution can be used to reconstruct marsh zones within sediment cores (figure 9.1b).



(a) Competing hypotheses



(b) Foraminiferal marsh zones

Figure 9.1.: Photos showing Tollesbury saltmarsh with its typical vegetation and creeks by low tide (a) Competing hypotheses: hypothesis 1 where the marsh develops from low to high, whereas hypothesis 2 shows a marsh succession from high to low, and (b) Foraminiferal marsh zones: common occurring Foraminifera species on the saltmarsh surface (left: agglutinated, right: calcareous) which help identify the succession of marsh zones in sediment cores of different developed saltmarshes.

The results for the Ostracoda assemblages showed too much variance not only within the marsh zones but also between different saltmarsh sites. Therefore, they could not be used as marsh zones indicator, besides their tendency for a patchy distribution. Furthermore, the absolute abundance of Ostracoda species per sample is very low when compared with the results obtained for Foraminifera. And in the northern sampling sites, hardly any Ostracoda were found et all, except for a high abundance of *Cyprideis torosa* at Kyleakin. In the sediment cores, even fewer Ostracoda specimens were found, and when present, than only in the cores of the southern study sites.

The analysed saltmarsh sediment cores show that for three study sites, Two Tree Island, Loch Riddon and Kyleakin, a saltmarsh succession of low to high marsh was found, this development of marsh zones supports hypothesis 1 (figure 9.2). For the remaining five study sites, Tollesbury, Gann, Loch Ainort, Loch Sligachan and Holkham, the marsh in the extracted sediment cores developed from high to low marsh or only high(-mid) marsh throughout, which supports hypothesis 2. The predicted marsh succession of the cores cannot be separated into a north-south divide, due to a probable more complicated relative sea-level history and land movement in the respected areas. Therefore, a more detailed analysis of each marsh with several cores along transects would be needed to understand its development better. Also, these results indicate that the text-book explanation (hypothesis 1) of most saltmarsh formation is not universally applicable and our appreciation of the relationship between SLR and saltmarshes needs to be reconsidered, to better predict the consequences of future increased rates of SLR.

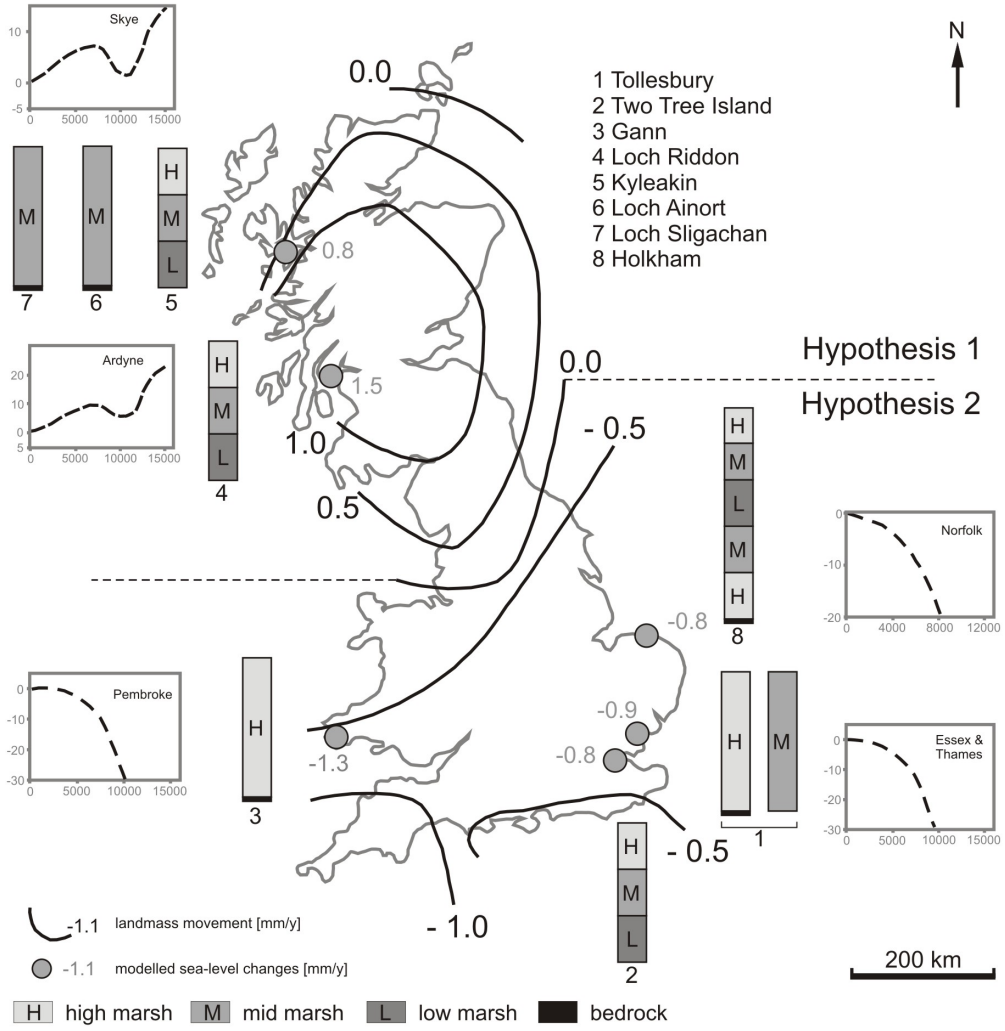


Figure 9.2.: UK with late Holocene land / sea-level changes [mm / year] including relative sea-level curves for all study sites (modified after Shennan & Horton, 2002). The zero line (dashed) indicates the boundary between subsiding and rising land, expecting to find hypothesis 1 in the north and hypothesis 2 in the south. Also, at least one core summarises the marsh succession per sampling site (1 to 8).

One problem was that not all sediment cores showed a complete saltmarsh record (reaching bedrock) as well as missing dates when the marsh was formed, and could be correlated to relative sea-level records. Therefore, due to high costs, only the marsh at the main study site at Tollesbury was dated with four age dating methods (^{14}C, OSL, ^{137}Cs & ^{210}Pb). The dated saltmarsh sediment from the Tollesbury site show that the marsh was formed around 4967 ± 65 Cal BP and was growing with 1.6 mm per year which could indicate a relative sea-level rise starting at 3.6 m depth and slowed down at 2.8 m depth with sedimentation rate of 0.82 mm per year. Then a relative sea-level drop can be dated with 3267 ± 67 Cal BP which is indicated by a following decrease in Foraminifera abundance above 2 m, correlating with the IV regression of around 3 000 years BP ago. However, a relative sea-level rise must have been occurred thereafter, due to the high sedimentation rate for the top 2 m with 1.6 mm per year. Then for 59 years this rate slowed down to 0.71 mm per year only to be followed for the top 7 cm marsh sediment with 0.26 mm per year, which would indicate a slowing down of the current relative sea-level rise.

Another problem was the missing calcareous Foraminifera (and Ostracoda) in core samples. Therefore, a dissolution experiment tested the hypothesis if this absences in sediment core samples was because they dissolved in the saltmarsh sediment. Samples with four different species were prepared and placed in sediment core water (CW), as well as *Ammonia* spp. was placed in Atlantic seawater (ASW) which functioned as a control. Then, four measurement campaigns were done spread over six months, measuring the total alkalinity and pH of the water (ASW and CW) with and without Foraminifera tests. The resulting values were compared to a CW and ASW reference line. Both, the alkalinity as well as the pH values showed, that no to only a slightly solution occurred, which does not support the hypothesis. The SEM images of the remaining tests also showed no traces of dissolution, which also does not support the hypothesis. Furthermore, diatom analyses of all sediment core samples revealed that probably not dissolution is responsible for the absence of calcareous Foraminifera in the sediment cores, but the habitat was not suitable (e.g. high marsh) for their living preferences. This concludes that even though saltmarsh water, on the surface as well as in the sediment, has a low pH, it is not enough to dissolve calcareous Foraminifera. However, the dissolution experiment should be repeated to gain results which are not influenced by contaminated equipment, and to test different core waters from other saltmarshes as well. Also, more studies on diatoms need to be conducted, to test for example, if at Loch Riddon saltmarsh really no diatoms are present in the sediment.

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A. Plants

In appendix A, all plants that were identified from the saltmarsh sites are listed in alphabetical order including their common names:

Agrostis stolonifera (creeping bentgrass, creeping bent, fiorin, spreading bent, carpet bentgrass, redtop)
Agrostis sp.
Armeria maritima (thrift, sea thrift, sea pink)
Aster tripolium (sea aster)
Atriplex (*Halimione*) *portulacoides* (sea purslane)
Bolboschoenus maritimus (sea clubrush, cosmopolitan bulrush, alkali bulrush, saltmarsh bulrush, bayonet grass)
Cochlearia anglica (English scurvygrass, long-leaved scurvy grass)
Elytrigia (*Elymus*) *atherica* (sea couch grass)
Elytrigia (*Elymus*) *repens* (common couch, twitch, quick grass, quitch grass, dog grass, quackgrass, scutch grass, witchgrass)
Festuca rubra (red fescue, creeping red fescue)
Fucus cottonii (moss wrack)
Glaux maritima (sea milkwort, sea milkweed, black saltwort)
Juncus ambiguus (toad rush)
Juncus bufonius (toad rush)
Juncus gerardii (saltmarsh rush)
Juncus sp.
Limonium bellidifolium (matted sea lavender)
Phragmites australis (common reed)
Plantago coronopus (buck's-horn plantain, minutina, erba stella)
Plantago maritima (sea plantain, seaside plantain, goose tongue)
Puccinellia maritima (seaside alkali grass, common saltmarsh-grass, sea poa grass)
Salicornia europaea (marsh samphire, common glasswort)

Salicornia ramosissima (purple glasswort)

Spartina anglica (common cord-grass)

Suaeda fruticosa

Suaeda vera (shrubby sea blite)

Triglochin maritima (common arrowgrass, sea arrowgrass, shore arrowgrass and seaside arrowgrass)

Trifolium repens (white clover, Dutch clover)

B. Sample list including sieved residue and total specimen numbers

Appendix B lists all saltmarsh surface and core samples, where tables show for each sample, the surface position (from what plant zone) or the depth for each core sample (in cm depth). The sample number (Sample) identifies each individual sample. Furthermore, the dried sieved residue in gram [g] for the sieve sizes $>$ 1 mm (1 mm [g]) and 1 mm to 125 µm (125 µm [g]) is shown for each sample. Only the sediment with the size 1 mm to 125 µm was sorted through and analysed for microfossils, due to reasons explained in chapter 4. Therefore, the examined sediment (EX 125 µm [g]) as well as the absolute abundance of Ostracoda and Foraminifera specimens are shown here. In total, 244 samples containing 8 196 Ostracoda and 58 601 Foraminifera were analysed.

Table B.1.: 17 surface samples from Tollesbury saltmarsh, including samples from high (E 2 to P 3), mid (A 2 and AA 1) and low marsh (S 2 to CR 2). The salt pan samples were collected from high (SP 1, SP 3) as well as mid marsh (SP 4, SP 8) areas.

Sample position	**Sample**	**1 mm [g]**	**125 µm [g]**	**EX 125 µm [g]**	**Ostracoda**	**Foraminifera**
Elytrigia	E 2	2.0087	8.3559	0.2819	0	176
Elytrigia	E 9	1.8548	2.9688	0.1453	4	938
plant sample	Terr.	23.2234	0.5493	0.5493	49	553
Puccinellia	P 3	1.4677	6.1636	0.0114	0	564
Atriplex sediment	AS (A 2)	0.8326	2.6682	0.0694	15	688
Atriplex algae	AA (AA 1)	4.5884	1.3999	0.9426	6	50
Salicornia	S 2	4.9825	2.8813	0.0984	6	511
Salicornia	S 4	0.8129	1.6218	0.0431	30	505
Salicornia	S 8	0.7532	2.0164	0.0310	6	608
Salt pan	SP 1	0.1575	2.5217	0.0734	0	531
Salt pan	SP 3	0.7213	2.6868	1.1905	0	182
Salt pan	SP 4	0.6365	1.5305	0.0442	89	392

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Table B.1 – continued from previous page

Sample position	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
Salt pan	SP 8	1.1503	1.5168	0.0184	17	207
wet sed (creek bottom) 1	CB 1	0.3461	0.5578	0.0532	87	247
wet sed (creek bottom) 2	CB 2	0.1779	4.3917	0.0779	33	452
dry sed (creek rim) 1	CR 1	0.3359	1.7700	0.1203	127	633
dry sed (creek rim) 2	CR 2	1.7865	3.4151	0.0004	9	526

Table B.2.: From the Tollesbury saltmarsh, a 2.5 m sediment core (TCE) and a 5 m core (TC) was extracted. TCE was collected from the high marsh and separated into 25 samples. TC was taken from the mid marsh and divided into 50 samples, but only each third was analysed, which are shown here with a total of 17 samples.

Sample depth [cm]	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
0-10 cm	TCE 1	0.4070	3.6543	0.8469	0	151
10-20 cm	TCE 2	0.0985	1.6081	1.4952	0	228
20-30 cm	TCE 3	0.0385	0.6037	0.5394	0	127
30-40 cm	TCE 4	0.1684	1.1010	0.5385	0	207
40-50 cm	TCE 5	1.0455	0.9680	0.1274	0	297
50-60 cm	TCE 6	0.0858	1.2033	0.1039	0	330
60-70 cm	TCE 7	0.0287	0.4493	0.2344	0	303
70-80 cm	TCE 8	0.2160	0.9905	0.2238	0	187
80-90 cm	TCE 9	0.0180	0.5105	0.2144	0	326
90-100 cm	TCE 10	0.0402	0.6211	0.1919	0	344
100-110 cm	TCE 11	1.4685	0.6549	0.1224	0	429
110-120 cm	TCE 12	0.0840	0.8194	0.1620	0	398
120-130 cm	TCE 13	0.3472	1.7573	1.7573	0	24
130-140 cm	TCE 14	0.6285	3.0612	3.0612	0	52
140-150 cm	TCE 15	1.3015	2.4216	2.4216	0	38
150-160 cm	TCE 16	3.2316	2.5790	2.5790	0	42
160-170 cm	TCE 17	0.5693	1.6671	1.6671	0	34

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Table B.2 – continued from previous page

Sample depth [cm]	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
170-180 cm	TCE 18	0.2503	1.2782	1.2782	0	14
180-190 cm	TCE 19	0.4073	2.1225	2.1225	0	7
190-200 cm	TCE 20	1.7269	3.7922	3.7922	0	24
200-210 cm	TCE 21	0.5885	1.2753	1.2753	0	120
210-220 cm	TCE 22	0.9534	2.6746	2.6746	0	85
220-230 cm	TCE 23	15.0049	9.0746	9.0746	0	44
230-240 cm	TCE 24	22.5661	4.8886	4.8886	0	80
240-250 cm	TCE 25	0.0653	0.6628	0.6628	0	14
0-10 cm	TC 1	6.0337	1.8258	0.0477	0	241
30-40 cm	TC 4	0.0426	2.1899	0.0455	0	238
60-70 cm	TC 7	0.0121	0.5626	0.0381	0	303
90-100 cm	TC 10	0.0028	0.0901	0.0215	0	159
120-130 cm	TC 13	0.0100	0.2424	0.1869	0	185
150-160 cm	TC 16	0.0111	0.3044	0.0846	0	257
180-190 cm	TC 19	0.0334	0.2136	0.0573	0	255
210-220 cm	TC 22	0.0369	0.7013	0.0179	0	269
240-250 cm	TC 25	0.0123	0.2269	0.0932	0	177
270-280 cm	TC 28	0.0002	0.0680	0.0215	0	277
300-310 cm	TC 31	0.0192	0.2000	0.0277	0	278
330-340 cm	TC 34	0.0047	0.3171	0.1038	0	282
360-370 cm	TC 37	0.0051	8.4586	0.1883	0	131
390-400 cm	TC 40	0.0025	0.2137	0.0656	0	257
420-430 cm	TC 43	0.0042	0.3417	0.1293	0	277
450-460 cm	TC 46	0.0208	0.7017	0.1259	0	163
480-490 cm	TC 49	0.0078	0.3327	0.1014	0	185

Table B.3.: 48 surface samples for the seasonal study were collected from Tollesbury saltmarsh. The samples from high (E = *Elytrigia*), mid (A = *Atriplex*, AA = algae on *Atriplex*) and low marsh (Creek rim) zones were extracted each two months, between February 2012 to April 2013.

Sample position	**Sample**	**1 mm [g]**	**125 μm [g]**	**EX 125 μm [g]**	**Ostracoda**	**Foraminifera**
Elytrigia 2 (2cm)	E 4	0.2765	6.1730	0.1450	0	536
Elytrigia 3 (2cm)	E 5	0.5786	3.8054	0.1346	0	508
Atriplex 1 (2cm)	A 3	0.1954	2.3377	0.1275	17	482
Atriplex 5 (2cm)	A 7	0.1751	0.8758	0.0660	48	461
Atriplex algae 1 (A 1)	AA 2	5.1753	3.7162	3.7162	9	290
Low 1 (2cm, creek rim)	CR 3	0.0065	0.2790	0.2790	7	412
Low 5 (2cm, creek rim)	CR 7	0.0125	0.2599	0.2599	6	639
Elytrigia 2 (2cm)	E 12	1.1836	4.1565	0.1570	0	332
Elytrigia 3 (2cm)	E 13	0.9515	5.2862	0.1972	0	350
Atriplex 1 (2cm)	A 8	0.3463	1.4030	0.0401	35	480
Atriplex 5 (2cm)	A 12	0.6757	0.3882	0.0287	60	243
Atriplex algae 1 (A 1)	AA 4	2.5776	1.2189	1.2189	5	23
Low 1 (2cm, creek rim)	CR 8	0.0694	0.1308	0.0715	0	286
Low 5 (2cm, creek rim)	CR 12	0.0224	0.1884	0.0794	33	337
Elytrigia 2 (2cm)	E 18	0.5347	6.1087	0.2961	0	388
Elytrigia 3 (2cm)	E 19	0.3831	6.3840	0.2424	0	347
Atriplex 1 (2cm)	A 13	0.1935	1.3936	0.0214	39	495
Atriplex 5 (2cm)	A 17	0.2140	1.3905	0.0366	60	333
Atriplex algae 1 (A 1)	AA 6	3.9161	0.6930	0.6930	2	14
Low 1 (2cm, creek rim)	CR 13	0.0754	0.3014	0.1645	4	224
Low 5 (2cm, creek rim)	CR 17	0.0401	0.1360	0.0392	1	388
Elytrigia 2 (2cm)	E 23	0.4487	5.4236	0.1524	0	358
Elytrigia 3 (2cm)	E 24	0.6761	7.2559	0.1747	0	366
Atriplex 1 (2cm)	A 18	0.1475	2.2784	0.0154	15	264
Atriplex 5 (2cm)	A 22	0.2787	1.1998	0.3780	45	340

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Table B.3 – continued from previous page

Sample position	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
Atriplex algae 1 (A 1)	AA 8	3.9084	1.2829	0.0751	9	40
Low 1 (2cm, creek rim)	CR 18	0.0779	0.4380	0.2274	9	261
Low 5 (2cm, creek rim)	CR 22	0.0665	0.4086	0.0594	20	463
Elytrigia 2 (2cm)	E 28	0.4307	6.4155	1.9226	0	213
Elytrigia 3 (2cm)	E 29	0.4112	6.9318	0.4804	0	85
Atriplex 2 (2cm)	A 24	0.2426	1.6219	0.0133	19	366
Atriplex 5 (2cm)	A 27	0.3982	0.9336	0.0407	27	429
Atriplex algae 1 (A 1)	AA 10	3.0315	0.9650	0.9650	14	0
Low 1 (2cm, creek rim)	CR 23	0.0762	0.3052	0.1743	17	209
Low 5 (2cm, creek rim)	CR 27	0.0422	0.2352	0.0692	7	270
Elytrigia 2 (2cm)	E 33	2.4937	4.3272	0.3261	0	210
Elytrigia 3 (2cm)	E 34	0.4685	6.8380	0.3073	0	227
Atriplex 1 (2cm)	A 28	0.1503	0.9788	0.0461	21	230
Atriplex 5 (2cm)	A 32	0.1634	0.6289	0.0399	62	317
Atriplex algae 1 (A 1)	AA 12	3.8015	2.4671	2.4671	8	0
Low 1 (2cm, creek rim)	CR 28	0.0563	0.3083	0.1702	18	190
Low 5 (2cm, creek rim)	CR 32	0.0433	0.1822	0.0729	21	310
Elytrigia 2 (2cm)	E 38	1.4188	3.5551	0.3397	0	139
Elytrigia 3 (2cm)	E 39	0.5513	7.9611	0.3151	0	128
Atriplex 1 (2cm)	A 33	0.2121	1.8321	0.0490	15	303
Atriplex 5 (2cm)	A 37	0.1655	1.3671	0.0261	36	255
Atriplex algae 1 (A 1)	AA 14	2.1295	1.4697	1.4697	5	0
Low 1 (2cm, creek rim)	CR 33	0.0549	0.1665	0.1102	0	169
Low 5 (2cm, creek rim)	CR 37	0.0035	0.1349	0.0792	10	186
Elytrigia 2 (2cm)	E 43	0.7374	6.3276	0.1130	0	404
Elytrigia 3 (2cm)	E 44	0.4005	5.0061	0.2747	0	232
Atriplex 1 (2cm)	A 38	0.2203	1.0043	0.0183	7	263
Atriplex 5 (2cm)	A 42	0.2804	0.9348	0.0219	28	370

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Table B.3 – continued from previous page

Sample position	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
Atriplex algae 1 (A 1)	AA 16	5.4570	2.4877	2.4877	7	0
Low 1 (2cm, creek rim)	CR 38	0.0557	0.1832	0.0441	5	112
Low 5 (2cm, creek rim)	CR 42	0.0263	0.0997	0.0997	4	212

Table B.4.: From Two Tree Island saltmarsh, three surface samples (E 16, P 6, S 6) as well as a 4 m long sediment core (TCP) were collected. Surface samples were taken from high (E = *Elytrigia*), high-mid (P = *Puccinellia*) and low marsh (S = *Salicornia*). The core was extracted from the *Puccinellia* plant zone and divided into 40 samples. Only every third sample was analysed (13 in total).

Sample position / depth	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
Elytrigia (west)	E 16	2.2620	6.4675	0.3758	5	157
Puccinellia 2 (west)	P 6	0.9900	4.4284	0.1446	5	467
Salicornia 1 (west)	S 6	0.1073	2.1420	0.2242	417	672
0-10 cm	TCP 1	0.3080	2.2143	0.3951	9	188
30-40 cm	TCP 4	0.0608	2.3661	0.7631	0	315
60-70 cm	TCP 7	0.0214	0.7123	0.0687	12	401
90-100 cm	TCP 10	0.0000	0.2432	0.0585	31	424
120-130 cm	TCP 13	0.1213	0.3647	0.1380	68	552
150-160 cm	TCP 16	0.1234	0.4420	0.2184	213	430
180-190 cm	TCP 19	0.7063	0.5313	0.1355	121	580
210-220 cm	TCP 22	0.7253	0.7563	0.5330	63	341
240-250 cm	TCP 25	1.9553	1.4650	0.0549	307	425
270-280 cm	TCP 28	0.0776	0.7267	0.2163	181	552
300-310 cm	TCP 31	0.2157	0.6766	0.2160	94	274
330-340 cm	TCP 34	0.0894	1.3562	0.1585	347	313
360-370 cm	TCP 37	0.0141	1.1619	0.0549	437	347

Table B.5.: The Isle of Wight saltmarsh from the Western Yar Estuary was sampled for an Ostracoda study. Therefore, only surface samples were collected in April 2013 from a northern study site (R 1 to Ai 2), and re-sampled in February 2014 (R 3 to Mix 5) with additional sampling from a southern location (Mix 5 to HL 2).

Sample position	**Sample**	**1 mm [g]**	**125 μm [g]**	**EX 125 μm [g]**	**Ostracoda**
Rim 1	R 1	5.1785	2.0453	2.0453	152
Rim 2	R 2	1.3439	2.5588	2.5588	1
Algae 1 on sediment	Aos 1	4.1089	2.2122	2.2122	25
Algae 2 on sediment	Aos 2	4.6663	1.7438	1.7438	38
Low 1	L 1	6.7432	1.9472	1.9472	6
Low 2	L 2	7.6733	1.6906	1.6906	1
Atriplex out 1	Ao 1	4.7059	2.1427	2.1427	5
Atriplex out 2	Ao 2	4.7101	3.0796	3.0796	3
Salt pan	SP	1.3129	1.0829	1.0829	5
Mix 1	Mix 1	3.3269	1.8606	1.8606	11
Mix 2	Mix 2	9.0075	2.0200	2.0200	182
Atriplex inner 1	Ai 1	5.0714	3.2677	3.2677	8
Atriplex inner 2	Ai 2	8.1074	2.5698	2.5698	12
Rim 1 (MF 1)	R 3	9.0239	2.4193	1.4526	128
Rim 2 (MF 2)	R 4	2.2651	4.6894	4.4163	183
Algae 1 on sediment (MF/L 1)	Aos 3	10.5807	2.5144	0.4947	60
Algae 1 on sediment (MF/L 2)	Aos 4	11.3933	3.3152	1.4506	84
Mix 1	Mix 3	9.9762	2.6667	0.2255	25
Mix 2	Mix 4	6.4325	2.264	0.2309	9
Mix 3	Mix 5	4.9085	1.7929	0.1864	18
Mix	Mix 6	3.2509	1.3248	0.1571	52
High leaves (H sed)	HL 1	11.4882	0.3529	0.3529	8
High leaves	HL 2	2.9868	5.7763	0.4616	20

Table B.6.: Samples from the Gann saltmarsh were collected from high (E = *Elytrigia*, *Puccinellia*), mid (A = *Atriplex*) and low marsh (S = *Salicornia*) zones. In total, four surface samples and three, of approximately 1 m deep, sediment cores (T 2, T 3, T 4) were collected.

Sample position / depth	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
Elytrigia	E 1	4.5500	10.2386	0.2984	0	487
Puccinellia (wet)	P 1	2.7810	1.7740	0.3804	1	550
Atriplex (dry)	A 1	0.4860	2.2712	0.3176	55	1242
Salicornia	S 1	0.285	43.6311	23.7433	191	327
Core T2 P (0-25 cm)	T2 1	0.1215	4.2424	0.1035	0	421
Core T2 P (25-50 cm)	T2 2	0.0205	15.4739	15.4739	0	140
Core T2 P (50-72 cm)	T2 3	0.0351	20.2767	1.2280	0	304
Core T2 P (72-97 cm)	T2 4	0.0275	4.6716	0.2127	0	242
Core T3 P-A (0-25 cm)	T3 1	0.1781	2.9484	0.2718	9	336
Core T3 P-A (25-50 cm)	T3 2	0.2950	3.2643	0.2572	3	239
Core T3 P-A (50-75 cm)	T3 3	0.2086	3.0907	0.2687	1	227
Core T3 P-A (75-94 cm)	T3 4	0.1566	13.2717	0.8541	0	175
Core T4 S (0-25 cm)	T4 1	0.0139	13.9481	0.3492	1	267
Core T4 S (25-50 cm)	T4 2	0.0236	9.8439	0.7328	2	286
Core T4 S (50-75 cm)	T4 3	0.3227	14.8729	0.425	1	198
Core T4 S (75-95 cm)	T4 4	0.9267	23.3062	23.3062	1	252
Core T4 S (95-105 cm)	T4 5	0.0416	8.8733	1.495	5	204

Table B.7.: From Loch Riddon saltmarsh, four surface samples (up to MF) and three sediment cores (c I, c II, c III) were collected. Surface samples were extracted from a grazed (gr) and ungrazed (ungr) area, as well as the upper marsh (up) and mudflat (MF).

Sample position / depth	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
upper marsh	up	5.4977	2.5779	0.6288	0	224
grazed	gr	7.8459	10.6523	0.3044	0	148

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Table B.7 – continued from previous page

Sample position / depth	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
ungrazed	ungr	3.0169	16.0241	1.2347	0	230
sand (mudflat)	MF	3.0872	57.1797	4.3615	1	56
core I 1 (0-10cm)	cI 1	1.0836	5.3759	0.2799	0	161
core I 2 (10-20cm)	cI 2	1.2767	6.8823	0.1416	0	153
core I 3 (20-30cm)	cI 3	0.1943	6.5791	0.1362	0	178
core I 4 (30-40cm)	cI 4	0.2466	6.9962	0.1385	0	155
core I 5 (40-50cm)	cI 5	0.3401	4.2038	0.1121	0	197
core I 6 (50-60cm)	cI 6	0.7972	5.9389	0.3250	0	220
core II 1 (0-10cm)	cII 1	0.7236	7.6695	1.8291	0	438
core II 2 (10-20cm)	cII 2	0.6232	6.6087	1.2160	0	411
core II 3 (20-30cm)	cII 3	0.2686	6.3157	0.9566	0	358
core II 4 (30-40cm)	cII 4	0.3445	4.3811	1.0115	0	479
core II 5 (40-50cm)	cII 5	0.2623	3.9676	0.7705	0	527
core II 6 (50-60cm)	cII 6	0.1234	4.6538	0.8738	0	604
core II 7 (60-70cm)	cII 7	0.0187	1.4156	1.1153	0	725
core III 1 (0-10cm)	cIII 1	0.9384	23.7474	0.1395	0	577
core III 2 (10-20cm)	cIII 2	1.0804	16.0756	0.3506	0	465
core III 3 (20-30cm)	cIII 3	7.9734	30.4946	4.9104	0	71

Table B.8.: The saltmarsh near Kyleakin was sampled from high (cI sur) and low marsh (LM 2), as well as mudflat (MF) and salt pan (SPW). Two sediment cores (c I, c II) were taken with a length of 50 and 57 cm.

Sample position / depth	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
core 1 surface	cI sur	8.6477	1.8577	1.8577	0	310
low marsh	LM 2	8.5016	7.4993	0.2951	0	350
mudflat	MF	7.1894	33.1810	1.5738	214	386
Salt pan water	SPW	0.2196	3.2400	0.2382	372	142

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Table B.8 – continued from previous page

Sample position / depth	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
c I 1 (0-10 cm)	cI 1	1.145	0.6853	0.0737	0	447
c I 2 (10-20 cm)	cI 2	1.0338	1.2245	0.0733	0	355
c I 3 (20-30 cm)	cI 3	3.3821	3.6856	0.8102	0	223
c I 4 (30-40 cm)	cI 4	0.3547	2.6513	0.2921	0	304
c I 5 (40-50 cm)	cI 5	0.9883	1.7428	0.4267	0	246
c II 1 (0-10 cm)	cII 1	1.6587	1.2416	0.0426	0	275
c II 2 (10-20 cm)	cII 2	0.8617	2.4817	0.1713	0	245
c II 3 (20-30 cm)	cII 3	2.2698	3.1512	0.1304	0	381
c II 4 (30-40 cm)	cII 4	1.8766	3.3512	0.2731	0	143
c II 5 (40-50 cm)	cII 5	1.8679	4.9436	0.854	0	230
c II 6 (50-57 cm)	cII 6	4.8717	4.3582	2.1611	0	86

Table B.9.: From Loch Ainort saltmarsh, one surface sample (sur) was taken from the marsh plateau, as well as one sediment core (c I), with a length of 35 cm. Also, a 89 cm deep second core (c II) was taken from a heather on top of the saltmarsh.

Sample position / depth	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
surface	sur	4.2982	8.6784	2.9335	0	209
c I 1 (0-10 cm)	cI 1	2.4421	4.9911	1.7741	0	114
c I 2 (10-20 cm)	cI 2	2.4070	11.1091	0.5549	0	10
c I 3 (20-30 cm)	cI 3	2.6449	12.5830	1.9526	0	11
c I 4 (30-35 cm)	cI 4	0.8761	1.9689	1.8233	0	18
c II 1 (0-10 cm)	cII 1	0.6626	1.4615	0.1925	0	0
c II 2 (10-20 cm)	cII 2	2.6144	2.3627	0.3833	0	0
c II 3 (20-30 cm)	cII 3	1.6829	1.6522	0.2931	0	0
c II 4 (30-40 cm)	cII 4	0.7146	2.3129	0.4706	0	0
c II 5 (40-50 cm)	cII 5	0.8460	2.6265	0.3500	0	0

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Table B.9 – continued from previous page

Sample position / depth	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
c II 6 (50-60 cm)	cII 6	0.6946	3.1980	0.3388	0	0
c II 7 (60-70 cm)	cII 7	0.4701	2.5599	0.3533	0	5
c II 8 (70-80 cm)	cII 8	0.0379	3.3162	0.2450	0	22
c II 9 (80-89 cm)	cII 9	0.0554	1.4969	0.1701	0	19

Table B.10.: From Loch Sligachan saltmarsh, only a 42 cm deep sediment core (c I) was extracted from the marsh plateau.

Sample depth [cm]	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
c I 1 (0-10 cm)	cI 1	0.8665	8.8402	0.3870	0	231
c I 2 (10-20 cm)	cI 2	1.1742	18.8033	3.8550	0	230
c I 3 (20-30 cm)	cI 3	0.6774	15.5082	2.7015	0	123
c I 4 (30-40 cm)	cI 4	1.3205	15.6700	2.4274	0	259
c I 5 (40-42 cm)	cI 5	0.4310	3.5664	0.4460	0	214

Table B.11.: From Stiffkey saltmarsh, only surface samples were collected from the high (HM), mid (MM), and low marsh (LM 1) zones.

Sample position	Sample	1 mm [g]	125 μm [g]	EX 125 μm [g]	Ostracoda	Foraminifera
high marsh	HM	6.3513	11.6362	1.8458	0	233
mid marsh	MM	3.3124	2.7191	0.0592	0	290
low marsh / mudflat	LM 1	0.0877	358.5132	1.7937	0	2

Table B.12.: A 9 m deep sediment core (NNC 17) from Holkham saltmarsh was re-sampled at the BGS, where three sampled per metre were collected. Shown are the analysed twelve samples.

Sample depth [cm]	**Sample**	**1 mm [g]**	**125 μm [g]**	**EX 125 μm [g]**	**Ostracoda**	**Foraminifera**
Run 1, sample 1 (10-12cm)	R 1/1	0	0.8665	0.6157	0	75
Run 1, sample 2 (30-32cm)	R 1/2	0.0120	1.1180	1.1180	0	0
Run 1, sample 3 (50-52cm)	R 1/3	0	0.4302	0.4302	0	4
Run 2, sample 1 (15-17cm)	R 2/1	0	1.4419	1.4419	0	7
Run 3, sample 1 (24-26cm)	R 3/1	0	0.3529	0.3529	0	10
Run 4, sample 1 (12-14cm)	R 4/1	0.1101	1.2509	1.2509	1	257
Run 5, sample 1 (15-17cm)	R 5/1	0.7733	0.4560	0.4560	0	53
Run 6, sample 1 (20-22cm)	R 6/1	0.1493	0.1720	0.1720	0	87
Run 7, sample 1 (12-15cm)	R 7/1	0.2332	0.3426	0.3426	3	525
Run 8, sample 1 (10-12cm)	R 8/1	0.0964	1.2491	1.2491	0	314
Run 9, sample 1 (17-19cm)	R 9/1	0.0094	0.1854	0.1854	0	24
Run 9, sample 3 (69-72cm)	R 9/3	0.7593	0,6851	0.6851	0	0

C. Samples location and elevation data including saltmarsh surface measurements

Appendix C represents the GPS coordinates (latitude and longitude), including the data on elevation of most saltmarsh surface samples and sediment cores. The elevation is given as Ordinance Datum (O.D.) and Chart Datum (C.D.), in respect to the measured port which was extracted from the Admiralty Tide Tables (ATT) (Admiralty Tide Tables, 1977). Also, saltmarsh surface elevation points were measured for Tollesbury (transects and plant zones) and Nith (marsh terraces). For the sampling localities, Two Tree Island, Gann, Isle of Wight and Holkham with Stiffkey, no sampling spots were measured.

Table C.1.: Tollesbury surface samples, including seasonal samples (E 3 to CR 7) and sediment cores locations (latitude and longitude) with elevation data given in O.D. and C.D., n.d. = no data.

Sample	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
E 2	51.76481	0.84230281	3.18	5.33
E 9	51.76457	0.84257908	3.21	5.36
Terr.	n.d.	n.d.	n.d.	n.d.
P 3	51.764771	0.84268369	2.83	4.98
AS (A 2)	51.764833	0.84230952	2.47	4.62
AA (AA 1)	51.764835	0.84231623	2.34	4.49
S 2	51.764893	0.84282182	2.71	4.86
S 4	51.767362	0.84764846	2.30	4.45
S 8	n.d.	n.d.	n.d.	n.d.
SP 1	51.764285	0.84330767	2.89	5.04
SP 3	n.d.	n.d.	n.d.	n.d.
SP 4	n.d.	n.d.	n.d.	n.d.
SP 8	n.d.	n.d.	n.d.	n.d.
CB 1	51.764871	0.84234037	1.86	4.01

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Table C.1 – continued from previous page

Sample	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
CB 2	51.767293	0.84769674	1.74	3.89
CR 1	51.764874	0.8423578	2.19	4.34
CR 2	51.767295	0.84768064	1.94	4.09
core I (TCE)	51.764825	0.84232236	3.32	5.47
core II (c II)	51.764282	0.84339339	3.05	5.20
core III (TC)	51.767306	0.84756263	2.99	5.14
core IV (c IV)	51.764286	0.84338093	3.05	5.20
E 3	51.764810	0.84227326	3.27	5.42
E 4	51.764812	0.84228126	3.31	5.46
E 5	51.764815	0.84229265	3.30	5.45
E 6	51.764822	0.84231397	3.26	5.41
E 7	51.764834	0.84234125	3.22	5.37
A 3	51.764799	0.84224738	2.87	5.02
A 4	51.764820	0.84225999	2.95	5.10
A 5	51.764833	0.84227905	3.02	5.17
A 6	51.764850	0.84233176	2.89	5.04
A 7	51.764880	0.84240231	2.81	4.96
AA 2	51.764799	0.84224738	2.87	5.02
AA 3	51.764880	0.84240231	2.81	4.96
CR 3	51.764804	0.84223175	2.13	4.28
CR 4	51.764833	0.84225517	2.23	4.38
CR 5	51.764856	0.84230836	2.11	4.26
CR 6	51.764883	0.84235832	2.10	4.25
CR 7	51.764903	0.84239724	1.98	4.13

Table C.2.: Tollesbury saltmarsh transects (A, B and C) representing elevation data from marsh surface and creeks. Elevation data are given in O.D. and C.D..

Sample (surface)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
A1 (creek)	51.764155	0.84460562	2.31	4.46
A2 (marsh)	51.764174	0.84457781	3.23	5.38
A3 (creek)	51.764053	0.84438176	2.61	4.76
A4 (marsh)	51.764062	0.84438233	3.09	5.24
A5 (creek)	51.764050	0.84413517	2.51	4.66
A6 (marsh)	51.764032	0.84411957	3.18	5.33
A7 (creek)	51.764071	0.84400605	2.41	4.56
A8 (marsh)	51.764035	0.84400379	3.03	5.18
A9 (creek)	51.764167	0.84375120	2.31	4.46
A10 (marsh)	51.764131	0.84374894	3.11	5.26
A11 (creek)	51.764588	0.84345878	2.44	4.59
A12 (marsh)	51.764588	0.84342983	3.18	5.33
A13 (creek)	51.764635	0.84336029	2.22	4.37
A14 (marsh)	51.764654	0.84331800	3.17	5.32
A15 (creek)	51.764604	0.84316989	2.39	4.54
A16 (marsh)	51.764630	0.84321500	3.19	5.34
B1 (marsh)	51.765963	0.84571946	3.17	5.32
B2 (marsh)	51.765837	0.84536364	3.24	5.39
B3 (creek)	51.765864	0.84533639	1.96	4.11
B4 (marsh)	51.765756	0.84496723	3.19	5.34
B5 (creek)	51.765729	0.84498001	1.87	4.02
B6 (marsh)	51.765363	0.84487001	3.08	5.23
B7 (creek)	51.765371	0.84491400	1.76	3.91
B8 (marsh)	51.764919	0.84462468	3.25	5.40
B9 (creek)	51.764901	0.84462355	2.26	4.41
B10 (marsh)	51.764598	0.84415514	3.04	5.19
B11 (creek)	51.764599	0.84412620	2.07	4.22

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Table C.2 – continued from previous page

Sample (surface)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
B12 (marsh)	51.764488	0.84385836	3.06	5.21
B13 (creek)	51.764497	0.84387339	2.25	4.40
C1 (creek)	51.767378	0.84744648	2.17	4.32
C2 (marsh)	51.767395	0.84747655	3.16	5.31
C3 (creek)	51.767437	0.84723277	1.36	3.51
C4 (marsh)	51.767465	0.84719105	3.19	5.34
C5 (creek)	51.767540	0.84668844	1.58	3.73
C6 (marsh)	51.767558	0.84671852	3.16	5.31
C7 (creek)	51.767744	0.84609243	2.00	4.15
C8 (marsh)	51.767734	0.84613529	2.98	5.13
C9 (creek)	51.767490	0.84540971	1.37	3.52
C10 (marsh)	51.767498	0.84546817	2.94	5.09
C11 (creek)	51.766965	0.84518822	1.53	3.68
C12 (marsh)	51.766967	0.84513033	2.99	5.14
C13 (creek)	51.766391	0.84436940	1.53	3.68
C14 (marsh)	51.766383	0.84432542	3.10	5.25
C15 (creek)	51.765994	0.84367767	1.31	3.46
C16 (marsh)	51.766023	0.84359253	3.07	5.22
C17 (creek)	51.765603	0.84314572	1.59	3.74
C18 (marsh)	51.765613	0.84310287	3.16	5.31
C19 (creek)	51.764837	0.84206850	2.17	4.32
C20 (marsh)	51.764838	0.84203955	3.12	5.27

Table C.3.: Tollesbury saltmarsh plat zone elevation data, given in O.D. and C.D., see chapter 6.1.1 for detailed description.

Sample	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
E1 U1	51.764816	0.84228962	3.34	5.49

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Table C.3 – continued from previous page

Sample	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
E1 U2	51.764784	0.84243165	3.12	5.27
E1 U3	51.764648	0.84260147	3.18	5.33
E1 U4	51.764526	0.84265912	3.17	5.32
E1 U5	51.764528	0.84248143	3.65	5.80
E1 U6	51.764410	0.84257081	3.42	5.57
E1 U7	51.764238	0.84289366	3.54	5.69
E1 U8	51.764159	0.84308062	3.97	6.12
E1 L1	51.764834	0.84234339	3.17	5.32
E1 L2	51.764777	0.84241906	3.12	5.27
E1 L3	51.764630	0.84262349	3.08	5.23
E1 L4	51.764543	0.84265990	3.07	5.22
E1 L5	51.764536	0.84253142	3.10	5.25
E1 L6	51.764424	0.84263196	3.16	5.31
E1 L7	51.764261	0.84290887	3.17	5.32
E1 L8	51.764196	0.84308225	3.22	5.37
E1 L9	51.764095	0.84335520	3.18	5.33
P1 M1	51.764772	0.84273403	2.88	5.03
P1 M2	51.764768	0.84265565	2.91	5.06
P1 M3	51.764729	0.84260912	2.96	5.11
P1 M4	51.764704	0.84253734	2.97	5.12
P1 M5	51.764709	0.84261877	2.93	5.08
P1 M6	51.764716	0.84266662	2.73	4.88
P1 M7	51.764667	0.84264504	2.72	4.87
P1 M8	51.764626	0.84263586	3.04	5.19
P1 M9	51.764589	0.84266183	2.95	5.10
P1 M10	51.764558	0.84266543	3.04	5.19
A1 U1	51.764803	0.84226301	3.10	5.25
A1 U2	51.764810	0.84225396	3.02	5.17

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Table C.3 – continued from previous page

Sample	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
A1 U3	51.764845	0.84233957	3.03	5.18
A1 U4	51.764902	0.84232955	2.74	4.89
A1 U5	51.764910	0.84251198	2.89	5.04
A1 U6	51.764811	0.84249703	3.04	5.19
A1 U7	51.764812	0.84249700	3.04	5.19
A1 U8	51.764750	0.84236934	3.07	5.22
A1 U9	51.764819	0.84269742	2.96	5.11
A1 U10	51.764793	0.84283930	2.87	5.02
A1 L1	51.764793	0.84227097	2.53	4.68
A1 L2	51.764812	0.84224542	2.69	4.84
A1 L3	51.764854	0.84232836	2.72	4.87
A1 L4	51.764909	0.84233437	2.45	4.60
A1 L5	51.764916	0.84249967	2.51	4.66
A1 L6	51.764820	0.84248554	2.86	5.01
A1 L7	51.764821	0.84248574	2.89	5.04
A1 L8	51.764756	0.84235335	2.65	4.80
A1 L9	51.764813	0.84267496	2.63	4.78
A1 L10	51.764788	0.84282624	2.59	4.74
S1 U1	51.764875	0.84239093	2.84	4.99
S1 U2	51.764916	0.84250478	2.73	4.88
S1 U3	51.764929	0.84268281	2.86	5.01
S1 U4	51.764808	0.84257348	2.68	4.83
S1 U5	51.764818	0.84270437	2.94	5.09
S1 U6	51.764780	0.84289189	2.82	4.97
S1 L1	51.764896	0.84237249	1.92	4.07
S1 L2	51.764924	0.84248842	2.03	4.18
S1 L3	51.764942	0.84267265	2.36	4.51
S1 L4	51.764817	0.84259631	2.18	4.33
S1 L5	51.764818	0.84272957	1.95	4.10

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Table C.3 – continued from previous page

Sample	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
S1 L6	51.764793	0.84292139	2.05	4.20
P2 M1	51.764483	0.84383273	2.87	5.02
P2 M2	51.764532	0.84381032	2.83	4.98
P2 M3	51.764539	0.84378253	2.86	5.01
P2 M4	51.764553	0.84382311	2.79	4.94
P2 M5	51.764500	0.84429040	2.87	5.02
P2 M6	51.764487	0.84431133	2.81	4.96
P2 M7	51.764443	0.84432208	2.84	4.99
P2 M8	51.764434	0.84435908	2.76	4.91
A2 U1	51.764558	0.84379342	2.85	5.00
A2 U2	51.764410	0.84402367	2.84	4.99
A2 U3	51.764443	0.84435254	2.82	4.97
A2 U4	51.764436	0.84439399	2.80	4.95
A2 U5	51.764337	0.84435336	2.99	5.14
A2 U6	51.764990	0.84453750	2.99	5.14
A2 U7	51.764943	0.84481756	3.01	5.16
A2 U8	51.765417	0.84479278	2.99	5.14
A2 L1	51.764577	0.84376557	2.61	4.76
A2 L2	51.764416	0.84404319	2.56	4.71
A2 L3	51.764462	0.84435567	2.73	4.88
A2 L4	51.764434	0.84440594	2.50	4.65
A2 L5	51.764335	0.84437374	2.68	4.83
A2 L6	51.764990	0.84446255	2.88	5.03
A2 L7	51.764953	0.84483616	2.88	5.03
A2 L8	51.765418	0.84477734	2.91	5.06
S2 U1	51.764576	0.84381198	2.78	4.93
S2 U2	51.764514	0.84371854	2.78	4.93
S2 U3	51.764395	0.84404049	2.81	4.96

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Table C.3 – continued from previous page

Sample	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
S2 U4	51.764433	0.84435035	2.75	4.90
S2 U5	51.764415	0.84434715	2.72	4.87
S2 U6	51.764334	0.84436685	2.79	4.94
S2 U7	51.764928	0.84485507	2.57	4.72
S2 U8	51.765622	0.84493946	2.85	5.00
S2 L1	51.764593	0.84382907	1.70	3.85
S2 L2	51.764514	0.84371854	2.00	4.15
S2 L3	51.764498	0.84372853	2.01	4.16
S2 L4	51.764417	0.84437477	1.99	4.14
S2 L5	51.764417	0.84437477	1.75	3.90
S2 L6	51.764315	0.84438240	1.90	4.05
S2 L7	51.764896	0.84488350	1.63	3.78
S2 L8	51.765643	0.84495533	2.24	4.39
A3 U1	51.765756	0.84516454	2.94	5.09
A3 U2	51.765708	0.84526267	2.95	5.10
A3 U3	51.765598	0.84527079	2.95	5.10
A3 U4	51.765670	0.84542055	3.08	5.23
A3 U5	51.765798	0.84537575	3.04	5.19
A3 L1	51.765775	0.84517655	2.74	4.89
A3 L2	51.765680	0.84520630	2.78	4.93
A3 L3	51.765603	0.84524598	2.71	4.86
A3 L4	51.765677	0.84545591	2.86	5.01
A3 L5	51.765788	0.84534468	2.77	4.92

Table C.4.: Grange-over-Sands surface samples and sediment core locations (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
Puccinellia high (Ph)	54.199344	-2.8871311	5.11	9.86
Puccinellia low (Pl)	54.199355	-2.8852053	4.03	8.77
salt pan (SP)	54.199140	-2.8851222	4.08	8.83
mudflat (MF)	54.199140	-2.8846581	3.64	8.39
core (C)	54.199324	-2.8852428	4.99	9.74

Table C.5.: Roudsea Woods surface samples and sediment core locations (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
Elytrigia (E)	54.226269	-3.0309659	4.93	9.83
Puccinellia (P)	54.228608	-3.0338439	3.96	8.86
low marsh (LM)	54.226012	-3.0313280	3.51	8.41
mudflat (MF)	54.225974	-3.0314460	3.40	8.30
core (C)	54.228972	-3.0342677	4.63	9.53

Table C.6.: Drumburgh surface samples and sediment cores locations (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
terrace high (TH)	54.938874	-3.1630258	5.72	7.82
terrace middle (TM)	54.939017	-3.1629802	5.10	7.20
terrace low (TL)	54.939083	-3.1628649	3.90	6.00
mudflat (MF)	54.939174	-3.1626637	3.25	5.35
terrace high core (cI)	54.938888	-3.1630768	5.78	7.88

Continued on next page

Table C.6 – continued from previous page

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
terrace middle core (cII)	54.938995	-3.1628864	5.19	7.29
terrace low core (cIII)	54.939065	-3.1628059	3.91	6.01

Table C.7.: Nith surface samples and sediment cores locations (latitude and longitude) with elevation data given in O.D. and C.D.. Also, elevation points of terrace high 1 to 10 and terrace low 1 to 10 were measured.

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
terrace high (TH)	54.979879	-3.5570906	5.12	9.22
terrace low (TL)	54.979883	-3.5573883	4.71	8.81
mudflat (MF)	54.979906	-3.5577263	3.59	7.69
core I (terrace high)	54.979875	-3.5575332	5.18	9.28
core II (mudflat)	54.979915	-3.5576190	4.02	8.12
terrace high 1 (TH 1)	54.979990	-3.5576190	5.22	9.32
terrace high 2 (TH 2)	54.979841	-3.5575546	5.14	9.24
terrace high 3 (TH 3)	54.979729	-3.5575251	5.11	9.21
terrace high 4 (TH 4)	54.979678	-3.5574795	5.20	9.30
terrace high 5 (TH 5)	54.979570	-3.5574608	5.08	9.18
terrace high 6 (TH 6)	54.979479	-3.5573776	5.09	9.19
terrace high 7 (TH 7)	54.979305	-3.5572703	5.16	9.26
terrace high 8 (TH 8)	54.979227	-3.5571845	5.09	9.19
terrace high 9 (TH 9)	54.979164	-3.5570236	5.01	9.11
terrace high 10 (TH 10)	54.979073	-3.5568868	5.12	9.22
terrace low 1 (TL 1)	54.980052	-3.5575895	4.70	8.80
terrace low 2 (TL 2)	54.979870	-3.5576110	4.69	8.79
terrace low 3 (TL 3)	54.979744	-3.5575707	4.45	8.55
terrace low 4 (TL 4)	54.979408	-3.5574393	4.67	8.77
terrace low 5 (TL 5)	54.979342	-3.5574152	4.67	8.77
terrace low 6 (TL 6)	54.979233	-3.5572515	4.72	8.82

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Table C.7 – continued from previous page

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
terrace low 7 (TL 7)	54.979111	-3.5570155	4.75	8.85
terrace low 8 (TL 8)	54.978982	-3.5568707	4.79	8.89
terrace low 9 (TL 9)	54.978871	-3.5568573	4.70	8.80
terrace low 10 (TL 10)	54.978708	-3.5564335	4.84	8.94

Table C.8.: Cree surface samples and sediment cores locations (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
surface high (sH)	54.892612	-4.3845735	3.08	6.81
surface core I (scI)	54.892654	-4.3847774	2.97	6.70
mudflat (MF)	54.892518	-4.3849625	1.90	5.63
core I (cI)	54.892603	-4.3847452	2.99	6.72
core II (cII)	54.892600	-4.3849061	1.95	5.68

Table C.9.: Arrochar surface sample and sediment cores locations (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
surface (sur)	56.206491	-4.7464652	1.30	2.92
core I (cI)	56.206476	-4.7465001	1.87	3.49
core II (cII)	56.206592	-4.7463606	1.60	3.22

Table C.10.: Loch Riddon surface samples and sediment cores locations (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
upper marsh (up)	55.979765	-5.1939435	1.70	3.32
grazed surface (gr)	55.979897	-5.1932649	1.33	2.95
ungrazed surface (ungr)	55.979945	-5.1933776	1.27	2.89
mudflat (MF)	55.979869	-5.1933534	0.86	2.48
core I (cI)	55.980191	-5.1934259	1.37	2.99
core II (cII)	55.979948	-5.1932622	1.35	2.97
core III (cIII)	55.979875	-5.1932354	0.88	2.50

Table C.11.: Kyleakin surface samples and sediment cores locations (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
surface high (sH)	57.271687	-5.7402827	2.22	4.95
surface low (sL)	57.271633	-5.7404570	2.13	4.86
salt pan (SP)	57.271332	-5.7405160	1.97	4.70
mudflat (MF)	57.271720	-5.7406153	0.97	3.70
core I (cI)	57.271736	-5.7402612	2.27	5.00
core II (cII)	57.271478	-5.7403980	2.17	4.90

Table C.12.: Loch Ainort surface sample and sediment cores locations (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
surface (sur)	57.269810	-6.0828330	2.50	5.15
core I (cI)	57.269818	-6.0827284	2.58	5.23

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Table C.12 – continued from previous page

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
core II (cII)	57.268521	-6.0838160	3.88	6.53

Table C.13.: Loch Sligachan sediment core location (latitude and longitude) with elevation data given in O.D. and C.D..

Sample (name)	Latitude	Longitude	Elevation O.D. [m]	Elevation C.D. [m]
core (C)	57.296999	-6.1616926	1.01	3.66

D. Absolute abundance of Foraminifera species

Appendix D, represents the absolute abundance of the identified Foraminifera species of all analysed samples (surface and sediment core samples). Also if counted, the amount of broken tests are shown (pieces) as well as the absolute abundance of all specimens per sample (total).

Table D.1.: 17 surface samples from Tollesbury saltmarsh, showing the absolute abundance of nine species per sample, as well as the absolute abundance of all specimens per sample (total) as well as their broken tests (pieces).

Sample name	***T. inflata***	***J. macrescens***	***M. fusca***	***R. moniliformis***	***C. involvens***	***Quinqueloculina* spp.**	***Ammonia* spp.**	***Elphidium* spp.**	***H. germanica***	**pieces**	**total**
E 2	80	95			1					1	176
E 9	120	800	10			8				17	938
Terr	152	371	2		6	19	3			15	553
P 3	140	406	10		1	7				7	564
AS (A 2)	38	302			105	240		2	1	6	688
AA (AA 1)	5	19			12	7		5	2	3	50
S 2	1	52			12	320	9	100	17	14	511
S 4	27	115			2	202	92	33	34	25	505
S 8	18	101	1		1	118	264	101	4	13	608
SP 1	167	290	59	15						47	531
SP 3	54	103	9	16							182
SP 4	69	43		11			24	14	231		392
SP 8	71	61	7	23			3	1	41		207

Continued on next page

Table D.1 – continued from previous page

Sample name	*T. inflata*	*J. macrescens*	*M. fusca*	*R. moniliformis*	*C. involvens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	pieces	total
CR 1	19	74			6	319	16	165	34	25	633
CR 2		12			5	495	2	10	2		526
CB 1	16	50			2	17	1	92	69	2	247
CB 2	119	286			2	8	5	8	24	7	452

Table D.2.: Table showing the absolute abundance of eight Foraminifera species per sediment core sample, as well as the amount of broken test (pieces). Also shown is the absolute abundance of all specimens per sample (total). The first 25 samples (TCE 1 to TCE 25) belong to the 2.5 m long sediment core (TCE) from Tollesbury saltmarsh. The 17 samples below (TC 1 to TC 49), are from the 5 m long sediment core (TC).

Sample name	*T. inflata*	*J. macrescens*	*M. fusca*	*C. involvens*	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	*Globigerina* spp.	pieces	total
TCE 1	73	76	2		1				3	151
TCE 2	32	190	4	1					11	228
TCE 3	127								8	127
TCE 4	79	125	3						18	207
TCE 5	91	205	1						14	297
TCE 6	226	101	3						10	330
TCE 7	207	93	3						27	303
TCE 8	121	66							14	187
TCE 9	193	129	4						29	326

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Table D.2 – continued from previous page

Sample name	*T. inflata*	*J. macrescens*	*M. fusca*	*C. involvens*	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	*Globigerina* spp.	pieces	total
TCE 10	169	174	1						25	344
TCE 11	146	279	4						19	429
TCE 12	148	241	9						36	398
TCE 13	8	16							18	24
TCE 14	23	28						1	3	53
TCE 15	23	15							3	38
TCE 16	21	21							1	42
TCE 17	20	14								34
TCE 18	9	4						1		15
TCE 19	5	2								7
TCE 20	11	12							1	24
TCE 21	42	75	3						10	120
TCE 22	37	47	1						11	85
TCE 23	22	22							9	44
TCE 24	37	43							10	80
TCE 25	8	6							3	14
TC 1	112	123								235
TC 4	186	52	5			1				244
TC 7	260	43								303
TC 10	68	91								159
TC 13	146	39								185
TC 16	50	207								257
TC 19	42	144			1	2	66			255
TC 22	198	71								269
TC 25	98	79								177

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Table D.2 – continued from previous page

Sample name	*T. inflata*	*J. macrescens*	*M. fusca*	*C. involvens*	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	*Globigerina* spp.	pieces	total
TC 28	90	124			6		7			227
TC 31	153	122			1		2			278
TC 34	84	193			4	1				282
TC 37	86	45				1				132
TC 40	113	144								257
TC 43	94	179					4			277
TC 46	79	84								163
TC 49	120	64					1			185

Table D.3.: 56 Tollesbury saltmarsh surface samples (seasonal study) from the high (E), mid (A), AA = algae growing on *Atriplex*) and low marsh (CR) zone, showing the absolute abundance of nine Foraminifera per sample. Also shown is the absolute abundance of specimens per sample (total), as well as broken tests (pieces).

Sample name	*T. inflata*	*J. macrescens*	*M. fusca*	*C. involvens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	*Globigerina* spp.	pieces	total
E 4	192	343	1							27	536
E 5	365	140			3					1	508
A 3	76	338		14	53		1			7	482
A 7	75	271		20	94		1			7	461
AA 2	13	232		2	22	1	5	15		1	290
CR 3	23	134		1	117	4	116	17		24	412

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Table D.3 – continued from previous page

Sample name	*T. inflata*	*J. macrescens*	*M. fusca*	*C. involvens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	*Globigerina* spp.	pieces	total
CR 7	20	158		9	34	223	188	7		17	639
E 12	52	280								13	332
E 13	67	279	2		1		1			22	350
A 8	138	304		6	31			1		9	480
A 12	62	130		9	39		3			10	243
AA 4	1	7	1	1	2		9	3		1	23
CR 8	17	124		2	131	2	6	3		28	286
CR 12	8	54		4	49	162	40	20		21	337
E 18	80	308								49	388
E 19	87	260								23	347
A 13	52	411		11	19		1	1		9	495
A 17	24	205		22	81		1			23	333
AA 6				3	8		1	2			14
CR 13	9	104			44	20	18	29		28	224
CR 17	22	122			18	114	106	6		22	388
E 23	58	300								33	358
E 24	166	198	1				1			45	366
A 18	38	199		1	26					12	264
A 22	34	148		10	127	9	11	1		15	340
AA 8	4	16		5	4	2	6	3		1	40
CR 18	24	132			89	1	10	5		15	261
CR 22	15	39			35	194	170	10		10	463
E 28	120	89	3						1	11	213

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Table D.3 – continued from previous page

Sample name	*T. inflata*	*J. macrescens*	*M. fusca*	*C. involvens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	*Globigerina* spp.	pieces	total
E 29	30	54	1							17	85
A 24	42	310			14					12	366
A 27	76	245		18	83	2	5			24	429
AA 10											
CR 23	18	93			25	33	16	24		28	209
CR 27	3	32			33	113	61	28		29	270
E 33	55	155								10	210
E 34	121	106								13	227
A 28	54	154		2	18		1	1		9	230
A 32	51	177		7	76	1	5			17	317
AA 12											
CR 28	14	102			42	2	26	4		17	190
CR 32	7	37			18	139	96	13		32	310
E 38	75	64								6	139
E 39	33	95								21	128
A 33	31	214			57			1		21	303
A 37	43	152		14	44		2			22	255
AA 14											
CR 33	20	104			12	16	3	14		22	169
CR 37	7	37			21	33	65	23		15	186
E 43	36	368								19	404
E 44	58	173	1							25	232
A 38	42	192		3	22		1	3		10	263

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Table D.3 – continued from previous page

Sample name	*T. inflata*	*J. macrescens*	*M. fusca*	*C. involvens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	*Globigerina* spp.	pieces	total
A 42	60	242	1	15	47	2	3			15	370
AA 16											
CR 38	8	47		1	25	4	21	6		15	112
CR 42	14	37		1	28	63	62	7		19	212

Table D.4.: 48 Tollesbury saltmarsh surface samples (seasonal study) representing the absolute abundance of Rose Bengal stained Foraminifera tests from nine species per sample. Also shown is the absolute abundance of specimens per sample (total). The samples were collected from the high (E), mid (A) and low marsh (CR) zone.

Sample name	*T. inflata*	*J. macrescens*	*C. involvens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	total
E 4	113	112						225
E 5	54	14						68
A 3	6	14	2					22
A 7	21	22	6	8		1		58
CR 3	3	18		28	2	71		122
CR 7	1	9	4	4	198	1		217
E 12	15	35						50
E 13	27	48						75

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Table D.4 – continued from previous page

Sample name	*T. inflata*	*J. macrescens*	*C. involvens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	total
A 8	13	60		8				81
A 12	29	28	2	11				70
CR 8	4	31		20				55
CR 12		9		10	69		1	89
E 18	9	12						21
E 19	21	17						38
A 13	9	51	4	5				69
A 17	4	72	7	29				112
CR 13		22		19	7	12	11	71
CR 17		17		7	47	89	1	161
E 23	24	77						101
E 24	55	42						97
A 18	6	65		13				84
A 22	9	64	5	33	5	7		123
CR 18	4	60		50		4	2	120
CR 22	1	21		11	109	124	6	272
E 28	60	52						112
E 29	24	26						50
A 24	21	134		4				159
A 27	31	119	9	16		1		176
CR 23		24		11	17	10	5	67
CR 27		3		18	56	47	5	129
E 33	28	93						121

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Table D.4 – continued from previous page

Sample name	*T. inflata*	*J. macrescens*	*C. involvens*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	total
E 34	53	56						109
A 28	27	64	1	3				95
A 32	13	68	5	16		3		105
CR 28	1	32		17	2	20		72
CR32		7		8	67	53	1	136
E 38	39	33						72
E 39	9	45						54
A 33	12	87	2	1				102
A 37	13	66	4	8		1		92
CR 33		27		8			1	36
CR 37		11		10		6	20	47
E 43	28	72						100
E 44	18	154						172
A 38	14	60						74
A 42	29	89	1	8				127
CR 38	1	16	1	19	2	1		40
CR 42	1	8	1	17	42		1	70

Table D.5.: The table is showing the absolute abundance of 12 Foraminifera species per sample, which were collected from the Two Tree Island saltmarsh. Also shown is the absolute abundance of specimens per sample (total), as well as broken tests (pieces). The three surface samples (E 16, P 6, S 6) were collected from the high (E), high-mid (P) and low marsh (S) zone. Below, 13 sediment core samples (TCP 1 to TCP 37) from a 4 m long sediment core (TCP) are shown.

Sample name	***T. inflata***	***J. macrescens***	***M. fusca***	***C. involvens***	***Quinqueloculina* spp.**	***Asterigerinata* spp.**	***Ammonia* spp.**	***Cibicies* spp.**	***Elphidium* spp.**	***H. germanica***	***Globigerina* spp.**	***Lagena* spp.**	**pieces**	**total**
E 16		1					37	1	17	99	2		4	157
P 6	31	59	7	2	19		80	7	20	239	1	2	16	467
S 6	21	15			6		450		37	142		1	26	672
TCP 1	38	36		4	18		64		15	13			7	188
TCP 4	167	132	14	1	1								22	315
TCP 7	6	18					6		20	350		1	16	401
TCP 10							3		24	397			7	424
TCP 13		2			1		57		37	454		1	15	552
TCP 16	3			1			125		37	264			12	430
TCP 19							19		43	518			39	580
TCP 22	2	1					89	2	21	223	1	2	5	341
TCP 25	53	3					106		85	175	3		25	425
TCP 28	1					13	169	8		338	8	15	44	552
TCP 31	3					1	74	7	26	157	1	5	12	274
TCP 34	1	2				11	122	11	36	124	2	4	24	313
TCP 37	1	1			12	12	115	23	57	119	6	2	36	348

Table D.6.: Table is showing the absolute abundance of nine Foraminifera species per sample, which were collected from the Gann saltmarsh. Also shown is the absolute abundance of specimens per sample (total), as well as broken tests (pieces). The four surface samples (E 1, P 1, A 1, S 1) were collected from the high (E), high-mid (P), mid (A) and low marsh (S) zone. Below, all samples from three sediment cores (T 2, T 3, T 4) are shown.

Sample name	***J. macrescens***	***T. inflata***	***M. fusca***	***C. involvens***	***Quinqueloculina* spp.**	***Allogromia* sp.**	***Ammonia* spp.**	***Elphidium* spp.**	***H. germanica***	**pieces**	**total**
E 1	419	31				7				8	457
P 1	221	239	60	2	24			1	3	8	550
A 1	64	692	137	189	73		1	50	36	41	1242
S 1	52	43	2	1	10		24	80	115	15	327
T2 1	12	355	8			6				15	381
T2 2	32	95								52	127
T2 3	12	267								13	279
T2 4	9	221								3	230
T3 1	4	178	16	1	80		2	25	21	9	327
T3 2	2	174	23		14			10	14	4	237
T3 3	7	118	13		33	2		15	29	8	217
T3 4	9	149				2	1		7	2	168
T4 1	4	210		1	8	1	1	22	13	12	260
T4 2	5	199	5		8	1	6	22	32	9	278
T4 3	9	121	1		23	1	4	9	21	3	189
T4 4	8	218	2		2			2	8	11	240
T4 5	6	112			23		1	27	28	9	197

Table D.7.: The table shows the absolute abundance of six Foraminifera species per sample, which were collected from the Loch Riddon saltmarsh. Also shown is the absolute abundance of specimens per sample (total). The four surface samples (up, gr, ungr, MF) were collected from the high (up) and mid marsh (gr, ungr), and mudflat (MF). Below, all samples from three sediment cores (c I, c II, c III) are shown.

Sample name	***T. inflata***	***J. macrescens***	***H. wilberti***	***M. fusca***	***Elphidium* spp.**	***Allogromia* sp.**	**total**
up		25	183	16			224
gr	41	80	4	23			148
ungr	90	115	2	23			230
MF		3	3	12	38		56
cI 1	2		146	13			161
cI 2	18	124		11			153
cI 3	34	116	4	24			178
cI 4	3	117	3	32			155
cI 5		84		113			197
cI 6	3	117		100			220
cII 1	29	375	1	33		15	438
cII 2	14	323	13	61		100	411
cII 3	3	252	1	102		74	358
cII 4	1	221	3	254		87	479
cII 5		102	2	423		8	527
cII 6	1	110		493		14	604
cII 7		225		500		41	725
cIII 1	28	134	7	408		36	577
cIII 2	16	112	4	333		33	465
cIII 3		17		54		3	71

Table D.8.: The table is showing the absolute abundance of four Foraminifera species per sample, which were collected from the Kyleakin saltmarsh. Also shown is the absolute abundance of specimens per sample (total). The four surface samples (cI sur, LM 2, MF, SPW) were collected from the high (cI sur) and low marsh zone (LM 2, SPW), as well as the mudflat (MF). Below, all samples from two sediment cores (c I, c II) are shown.

Sample name	***T. inflata***	***J. macrescens***	***H. wilberti***	***M. fusca***	**total**
cI sur	46	59	32	173	310
LM 2	211	17		122	350
MF	219	2		165	386
SPW	4			138	142
cI 1	86	118	31	212	447
cI 2	123	66	5	161	355
cI 3	120	67		36	223
cI 4	209	28		67	304
cI 5	129	41		76	246
cII 1	257	3		15	275
cII 2	112	26		107	245
cII 3	89	138		154	381
cII 4	15	20		108	143
cII 5	18	61		151	230
cII 6	33	48		5	86

Table D.9.: The table shows the absolute abundance of three Foraminifera species per sample, which were collected from the Loch Ainort saltmarsh. Also shown is the absolute abundance of specimens per sample (total), as well as broken tests (pieces). The only surface sample (surface) was collected from the mid marsh zone. Below, all samples from two sediment cores (c I, c II) are shown.

Sample name	***T. inflata***	***J. macrescens***	***M. fusca***	**pieces**	**total**
surface		150	59	1	209
cI 1		114			114
cI 2		10			10
cI 3		11			11
cI 4		18			18
cII 1					0
cII 2					0
cII 3					0
cII 4					0
cII 5					0
cII 6					0
cII 7		5		3	5
cII 8		12	10		22
cII 9	1	9	9		19

Table D.10.: The table is showing the absolute abundance of two Foraminifera species per sample, which were collected from the Loch Sliagchan saltmarsh. Also shown is the absolute abundance of specimens per sample (total), as well as broken tests (pieces). The five samples (cI 1 to cI 5) are from a 50 cm long sediment core (c I).

Sample name	***J. macrescens***	***M. fusca***	**pieces**	**total**
cI 1	136	95	31	231
cI 2	151	79	5	230
cI 3	39	84	12	123
cI 4	116	143	29	259
cI 5	161	30	23	214

Table D.11.: The table shows the absolute abundance of five Foraminifera species per sample, which were collected from the Stiffkey saltmarsh. Also shown is the absolute abundance of specimens per sample (total). Three surface samples (HM 1, MM 1, LM 1) were collected from the high (HM 1), mid (MM 1) and low marsh (LM 1) zones.

Sample name	***T. inflata***	***J. macrescens***	***M. fusca***	***Quinqueloculina* spp.**	***Elphidium* spp.**	**total**
HM 1	181	32	14	6		233
MM 1	239	16	24	8	3	290
LM 1		1		1		2

Table D.12.: Table showing the absolute abundance of six Foraminifera species per sample, which were collected from the Holkham saltmarsh. Also shown is the absolute abundance of specimens per sample (total) as well as broken tests (pieces). The 11 samples (R 1/1 to R 9/1) were sampled from a 9 m long sediment core (NNC 17).

Sample name	***T. inflata***	***J. macrescens***	***Ammonia* spp.**	***Elphidium* spp.**	***H. germanica***	***Globigerina* sp.**	**pieces**	**total**
R 1/1		75						75
R 1/2								0
R 1/3		4						4
R 2/1	2	1	4					7
R 3/1			4	3	3			10
R 4/1	23		65	30	139	6	8	263
R 5/1		25	5	1	22			53
R 6/1	1	40	9	1	36			87
R 7/1	8	41	34	6	436			525
R 8/1	13	3	21	6	271			314
R 9/1	23	1						24

E. Absolute abundance of Ostracoda species

Appendix E, represents the absolute abundance of the identified Ostracoda species of all analysed samples (surface and sediment core samples). Also if counted, the amount of broken shells are shown (pieces) as well as the absolute abundance of all specimens per sample (total).

Table E.1.: 13 surface samples from Tollesbury saltmarsh, showing the absolute abundance of 11 species per sample, which were collected from the high (E 9, Terr), mid (A 2, AA 1) and low marsh (S 2 to CR 2) zones. Also shown is the absolute abundance of specimens per sample (total) as well as broken shells (pieces).

Sample name	***C. gibba***	***C. torosa***	***H. rubida***	***L. baltica***	***L. castanea***	***L. ciliata***	***L. porcellanea***	***L. elliptica***	***L. malcomsoni***	***C. fischeri***	***Terrestricythere* sp.**	**pieces**	**total**
E 9				4									4
Terr							5				44	18	49
AS (A 2)		1			4	4			5		1	7	15
AA (AA 1)							4		1	1		3	6
S 2					1	1	3		1			2	6
S 4				7			1		22			23	30
S 8		1					5					2	6
SP 4		85	1		1		2					9	89
SP 8		14			3							5	17
CB 1		2		24	55		5	1				14	87
CB 2		1			23		8			1		1	33
CR 1					84		22		20		1	63	127
CR 2	1				1	1			5	1		1	9

Table E.2.: The table is showing the absolute abundance of nine Ostracoda species per surface sample, including the absolute abundance of specimens per sample (total), as well as broken shells (pieces). The represented 40 samples from the seasonal study were collected from the Tollesbury saltmarsh from different marsh zones: mid (A, AA) and low marsh (CR) zone.

Sample name	***C. torosa***	***H. rubida***	***L. castanea***	***L. ciliata***	***L. porcellanea***	***E. baltica***	***L. malcomsoni***	***C. fischeri***	***Terrestricythere* sp.**	**pieces**	**total**
A 3	1			12			3		1	6	17
A 7				26	2		20			26	48
AA 2	1			1	2		2		3	4	9
CR 3				4	2		1			7	7
CR 7				3			3			2	6
A 8				18	3		14			22	35
A 12				22	7		31			24	60
AA 4					4			1		3	5
CR 12				5	7		20		1	7	33
A 13				12	15		11	1		15	39
A 17		1		34	12	2	11				60
AA 6					1	1				2	2
CR 13				1	3					2	4
CR 17					1						1
A 18	1	2		4	2		6			9	15
A 22				44	1					36	45
AA 8	1				6	1		1		1	9
CR 18			1	6	2					5	9
CR 22			7	1	10		2			2	20
A 24					13		3		3	11	19

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Table E.2 – continued from previous page

Sample name	*C. torosa*	*H. rubida*	*L. castanea*	*L. ciliata*	*L. porcellanea*	*E. baltica*	*L. malcomsoni*	*C. fischeri*	*Terrestricythere* sp.	pieces	total
A 27				2	23		2			36	27
AA 10	8			3	3						14
CR 23				1	13		3			9	17
CR 27	1			2	2		2			5	7
A 28			4	7	7		3			5	21
A 32			7	30	15		10			24	62
AA 12	4			2	2					3	8
CR 28		1	1	12			4			3	18
CR 32			14	1	4		2			2	21
A 33			1	4	3		7			21	15
A 37			4	8	16		7	1		20	36
AA 14	2				3					1	5
CR 33										1	0
CR 37			2		8					2	10
A 38				1	3		2		1	10	7
A 42			13	8	1		2		4	19	28
AA 16	5			1	1					2	7
CR 38					5					1	5
CR 42			2		2					3	4

Table E.3.: 32 Tollesbury saltmarsh surface samples (seasonal study), showing the absolute abundance of five living Ostracoda species per sample, as well as the absolute abundance of specimens (total). The samples were collected from the mid (A) and low marsh (CR) zones.

Sample name	***H. rubida***	***L. castanea***	***L. ciliata***	***L. porcellanea***	***L. malcomsoni***	**total**
A 3			1			1
A 7			10			10
CR 3			2			2
CR 7						0
A 8			1		3	4
A 12			2			2
CR 8						0
CR 12			1	2		3
A 13			1	2	1	4
A 17	1		9			10
CR 13				1		1
CR 17						0
A 18			3	1	1	5
A 22			9			9
CR 18				1		1
CR 22		2	1	1		4
A 24					1	1
A 27			2	5	1	8
CR 23						0
CR 27			1			1
A 28			2			2
A 32			6		1	7

Continued

Table E.3 – continued

Sample name	*H. rubida*	*L. castanea*	*L. ciliata*	*L. porcellanea*	*L. malcomsoni*	toal
CR 28						0
CR32		2		2		4
A 33			2			2
A 37					1	1
CR 33						0
CR 37						0
A 38						0
A 42			2			2
CR 38						0
CR 42						0

Table E.4.: 14-months time period of the Ostracoda seasonal study, showing the absolute abundance of the carapaces and valves every two months for the three most common species *L. malcomsoni*, *L. ciliata* and *L. porcellanea* at Tollesbury saltmarsh.

Ostracoda	February 2012	April 2012	June 2012	August 2012	October 2012	December 2012	February 2013	April 2013
carapaces	20	18	7	1	5	6	2	3
valves	20	34	7	9	16	14	24	13
carapaces	48	29	54	60	34	52	47	32
valves	5	8	15	18	10	11	8	19
carapaces	6	4	2	3	10	6	2	13

Continued

Table E.4 – continued

Ostracoda	February 2012	April 2012	June 2012	August 2012	October 2012	December 2012	February 2013	April 2013
valves	2	7	16	9	25	11	18	19

Table E.5.: PART 1: The table is showing the absolute abundance of 15 Ostracoda species per sample, which were collected from the Two Tree Island saltmarsh. The three surface samples (E 16, P 6, S 6) were collected from the high (E), high-mid (P) and low marsh (S) zone. Below, 13 sediment core samples (TCP 1 to TCP 37) from a 4 m long sediment core (TCP) are shown.

	P. elongata	*C. gibba*	*C. torosa*	*C.* cf. *depressum*	*C.* cf. *monoceros*	*C. punctatum*	*H. cellulosa*	*Hemicytherura* sp.	*Microcytherura* sp.	*Semicytherura* sp.	*A. woutersi*	*H. villosa*	*H. albomaculata*	*L. castanea*	*L. ciliata*
E 16															
P 6		1													
S 6										1				283	1
TCP 1													8		1
TCP 7			2												
TCP 10			9											2	
TCP 13														29	
TCP 16			9	3									1	102	
TCP 19			96											8	
TCP 22	1		6	2									1	27	
TCP 25	7		50		1	1				2		2		28	
TCP 28	19		16			5	4			17		4	4	15	
TCP 31	8		12		5	5			1	10			2	5	
TCP 34	25		24	5		20	12		7	29		9	11		

Continued on next page

Table E.5 – continued from previous page

Sample name	*P. elongata*	*C. gibba*	*C. torosa*	*C.* cf. *depressum*	*C.* cf. *monoceros*	*C. punctatum*	*H. cellulosa*	*Hemicytherura* sp.	*Microcytherura* sp.	*Semicytherura* sp.	*A. wouteri*	*H. villosa*	*H. albomaculata*	*L. castanea*
TCP 37	24		27			28	7	2	9	25	9	7	16	57

Table E.6.: PART 2: The table shows the absolute abundance of 13 Ostracoda species per sample, which were collected from the Two Tree Island saltmarsh. Also shown is the absolute abundance of specimens per sample (total), as well as broken shells (pieces). The three surface samples (E 16, P 6, S 6) were collected from the high (E), high-mid (P) and low marsh (S) zone. Below, 13 sediment core samples (TCP 1 to TCP 37) from a 4 m long sediment core (TCP) are shown.

	L.porcellanea	*L. psammophila*	*H. viridis*	*L. elliptica*	*L. rhomboidea*	*P. laevata*	*C. fischeri*	*Cytherois* sp.	*P. ensiforme*	*P. trieri*	*C.* cf. *whitei*	*H.* cf. *emaciata*	*Xestoleberis* sp.	pieces	total
E 16	2			3										4	5
P 6	1			3										9	5
S 6	106			15			6			5				97	417
TCP 1														5	9
TCP 7	10													7	12
TCP 10	18	2												14	31
TCP 13	36			1			2							9	68
TCP 16	94					3	1							39	213
TCP 19	17													53	121
TCP 22	22		1	2		1								26	63
TCP 25	114	6	8	81			3					4		46	307
TCP 28	44		23	21	4			2					3	63	181
TCP 31			12	10								5	19	44	94

Continued on next page

Table E.6 – continued from previous page

Sample name	*L.porcellanea*	*L. psammophila*	*H. viridis*	*L. elliptica*	*L. rhomboidea*	*P. laevata*	*C. fischeri*	*Cytherois* sp.	*P. ensiforme*	*P. trieri*	*C.* cf. *whitei*	*H.* cf. *emaciata*	*Xestoleberis* sp.	pieces	toal
TCP 34	64	49	32	34		4			4	5		8	5	97	347
TCP 37		89	34	45		17		9	2		2	20	8		437

Table E.7.: The table is showing the absolute abundance of 13 Ostracoda species per sample, which were collected from the saltmarsh at the Western Yar Estuary on the Isle of Wight. Also shown is the absolute abundance of specimens per sample (total), as well as broken shells (pieces). All 13 analysed samples were collected for a study on rare saltmarsh Ostracoda, see chapter 6.4 for description.

Sample name	*C. torosa*	*H. rubida*	*L. castanea*	*L. ciliata*	*L. fabaeformis*	*L. porcellanea*	*H. viridis*	*L. rhomboidea*	*C. fischeri*	*C.* cf. *stephanidesi*	*P. trieri*	*X. labiata*	*Terrestricythere* sp.	pieces	total
R 1	1		43	7	9	10		3			7	72		49	152
R 2				1											1
Aas 1			5	1	1	7			1			10			25
Aas 2	8		18	4		1					3	4		18	38
L 1			2			1		1				2			6
L 2						1									1
Ao 1		4										1			5
Ao 2													3	2	3
SP 2			3			1						1			5
Mix 1		7	2							2					11
Mix 2		160	13	1		1				7				26	182
Ai 1		4	3									1			8
Ai 2		11	1												12

Continued on next page

Table E.7 – continued from previous page

Sample name	*C. torosa*	*H. rubida*	*L. castanea*	*L. ciliata*	*L. fabaeformis*	*L. porcellanea*	*H. viridis*	*L. rhomboidea*	*C. fischeri*	*C.* cf. *stephanidesi*	*P. trieri*	*X. labiata*	*Terrestricythere* sp.	pieces	total
R 3			38	1	2	21	1		7		39	19		3	128
R 4			77		3	65					10	28		9	183
Aas 3			21			18					14	7		1	60
Aas 4			53	6		20					4	1			84
Mix 3		18	2			2					3				25
Mix 4		6	2							1					9
Mix 5		9		7							1	1		3	18
Mix 6		51								1				2	52
HL 1													8	1	8
HL 2													20		20

Table E.8.: The table is showing the absolute abundance of eight Ostracoda species per sample, including the absolute abundance of specimens per sample (total), as well as broken shells (pieces). All represented samples were collected from the Gann saltmarsh. The three surface samples (P 1, A 1, S 1) were collected from the high-mid (P), mid (A) and low marsh (S) zone. Below, all samples from two sediment cores (T 3, T 4) are shown.

Sample name	*C. gibba*	*L. baltica*	*L. castanea*	*L. ciliata*	*L. porcellanea*	*L. elliptica*	*E. baltica*	*C. fischeri*	pieces	total
P 1						1				1
A 1		3			10	42			11	55
S 1	1		3	2	14	162	6	3	33	191
T3 1						9			7	9

Continued on next page

Table E.8 – continued from previous page

Sample name	*C. gibba*	*L. baltica*	*L. castanea*	*L. ciliata*	*L. porcellanea*	*L. elliptica*	*E. baltica*	*C. fischeri*	pieces	total
T3 2						3			1	3
T3 3						1			2	1
T3 4										0
T4 1						1				1
T4 2						1		1	1	2
T4 3						1			4	1
T4 4						1				1
T4 5						5			6	5

Table E.9.: The table shows the absolute abundance of one Ostracoda species from the mudflat sample of the Loch Riddon saltmarsh. Also, shown is the amount of broken shells (pieces).

Sample name	*L. castanea*	pieces	total
MF	1	2	1

Table E.10.: Table showing the absolute abundance of one Ostracoda specie per sample, including the absolute abundance of specimens per sample (total), as well as broken shells (pieces). All samples were collected from the Kyleakin saltmarsh. The two surface samples (MF, SPW) were collected from the low marsh zone (SPW) and mudflat (MF).

Sample name	***C. torosa***	**pieces**	**total**
MF	214	13	214
SPW	372	35	372

Table E.11.: Table showing the absolute abundance of one Ostracoda species per sample, which were collected from the Holkham saltmarsh. Also shown is the absolute abundance of specimens per sample (total), as well as broken shells (pieces). The three samples (R 4/1 to R 7/1) are from a 9 m long sediment core (NNC 17).

Sample name	***L. porcellanea***	**pieces**	**total**
R 4/1	1	1	1
R 6/1		3	
R 7/1	3	5	3

F. Meiofauna sediment core data from previous projects

Appendix F, represents the absolute abundance of Foraminifera species per sample from two master projects (Palmisano, 2010; Janie, 2011). These data will be analysed and compared to the collected ones from this project in chapter **??**.

Table F.1.: The table shows the absolute abundance the most common Foraminifera species from a 3.33 m (EO), 2.91 m (PO) and 2.75 m (SOC) deep sediment cores extracted at Tollesbury saltmarsh (Janie, 2011).

Sample (depth)	***T. inflata***	***J. macrescens***	***M. fusca***	***Quinqueloculina* spp.**	***Ammonia* spp.**	**others**	**total**
1 (8-12 cm)	6				2		2
2 (34-38 cm)	14	34			1	1	36
3 (58.5-62.5 cm)	17	33			3		36
4 (82-86 cm)	38	14			2		16
5 (111-115 cm)	30	24	2		2		28
6 (118-122 cm)	32	22	1	1	4		28
7 (131-135 cm)	18	36			1	2	39
8 (147-151 cm)	4	8					8
9 (164-168 cm)	21	33	1		2		36
10 (179-183 cm)	1	2			1		3
11 (197-201 cm)	24	23	3		2	1	29
12 (214-218 cm)	22	23	2			4	29

Continued on next page

Table F.1 – continued from previous page

Sample (depth)	*T. inflata*	*J. macrescens*	*M. fusca*	*Quinqueloculina* spp.	*Ammonia* spp.	others	total
13 (230-234 cm)	15	31			3	1	35
14 (247-251 cm)	14	33			3	3	39
15 (264-268 cm)	5	10				1	11
16 (279-283 cm)	5	7			1		8
17 (297-301 cm)	14	26			1	1	28
18 (314-318 cm)	7	25		2	2	3	32
19 (329-333 cm)	16	14			1	1	16
1 (10-11 cm)	21	28			1		1
2 (30-31 cm)	22	31					0
3 (50-51 cm)	13	43			2		2
4 (70-71 cm)	12	36				2	2
5 (90-91 cm)	15	7			20		20
6 (110-111 cm)	14	32			8	2	10
7 (130-131 cm)	12	21			15		15
8 (150-151 cm)	8	30			3	1	4
9 (170-171 cm)	11	40			1		1
10 (190-191 cm)	20	34			1		1
11 (210-211 cm)	14	34			2		2
12 (230-231 cm)	12	38			2	2	4
13 (250-251 cm)	12	29			5		5
14 (270-271 cm)	5	38		1	1	1	3
15 (290-291 cm)	9	45				2	2
1 (10-11 cm)	7	32		10	11		60
2 (30-31 cm)	4	47			9	1	61

Continued on next page

Table F.1 – continued from previous page

Sample (depth)	*T. inflata*	*J. macrescens*	*M. fusca*	*Quinqueloculina* spp.	*Ammonia* spp.	others	total
3 (50-51 cm)	12	28		1	8	2	51
4 (67-68 cm)	10	38			1		49
5 (84-85 cm)	8	33		1	9	1	52
6 (114-115 cm)	15	30			8		53
7 (134-135 cm)	4	45				1	50
8 (154-155 cm)	8	42			6	1	57
9 (174-175 cm)	4	35			8	1	48
10 (194-195 cm)	2	43			3	1	49
11 (214-215 cm)	1	35			6		42
12 (234-235 cm)	4	43			6		53
13 (254-255 cm)	1	58			2		61
14 (274-275 cm)	5	25			8	1	39

Table F.2.: The table shows the absolute abundance of eight Foraminifera species per core sample as well as the absolute abundance of specimens (total). The 375 cm long sediment core (Core) was extracted from the Two Tree Island saltmarsh high marsh zone (Palmisano, 2010).

Sample (depth)	*J. macrescens*	*T. inflata*	*M. fusca*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	others	total
1 (0-15 cm)	128	6		5	1	3			143
2 (15-30 cm)	120	23					4		147

Continued on next page

Table F.2 – continued from previous page

Sample (depth)	*J. macrescens*	*T. inflata*	*M. fusca*	*Quinqueloculina* spp.	*Ammonia* spp.	*Elphidium* spp.	*H. germanica*	others	total
3 (30-45 cm)	99	23	3	6	2	1	2		136
4 (45-60 cm)	55	6		5	4	7	60	1	138
5 (60-75 cm)	13	1		2		12	119		147
6 (75-84 cm)	11			1		15	108	1	136
7 (84-99 cm)	43			4	2	8	78	4	139
8 (99-104 cm)	4	4			1	9	138	4	160
9 (104-119 cm)	1				4		139	4	148
10 (119-134 cm)		4			18	17	114	2	155
11 (134-149 cm)					15	9	111	1	136
12 (149-160 cm)	4	1		17		7	116		145
13 (160-175 cm)	11			25		5	104		145
14 (175-190 cm)	5			26		6	103		140
15 (190-205 cm)	4			38		2	100	4	148
16 (205-220 cm)	9			39		1	88	1	138
17 (220-235 cm)	8	1		48		5	83	7	152
18 (235-250 cm)	9	2		29		9	99	1	149
19 (250-265 cm)	13	1		20		3	107		144
20 (265-280 cm)	9			32		5	95	2	143
21 (280-295 cm)	8	4		28		9	100	1	150
22 (295-310 cm)	14	3		25		12	94	2	150
23 (310-325 cm)	13	5		34		30	66	2	150
24 (325-340 cm)	14	2		31		36	65	2	150
25 (340-355 cm)	15			7		8	111		141
26 (355-370 cm)				5		27	116	1	149
27 (370-375 cm)				6		13	119	5	143

G. Particle size analyses

Appendix G, contains data about all particle size analyses (PSA), showing figures of the grain size distribution (in µm) per sample, where the data can be downloaded from: `https://dl.dropboxusercontent.com/u/7890413/all%20PSA%20plot%20data.xls`. Also, tables with the relative abundance (%) of clay, silt and sand are represented for the sediment cores from Tollesbury (TCE, c II, TC), Gann (T 3, T 4), Loch Riddon (c I, c II, c III) and Holkham (NNC 17).

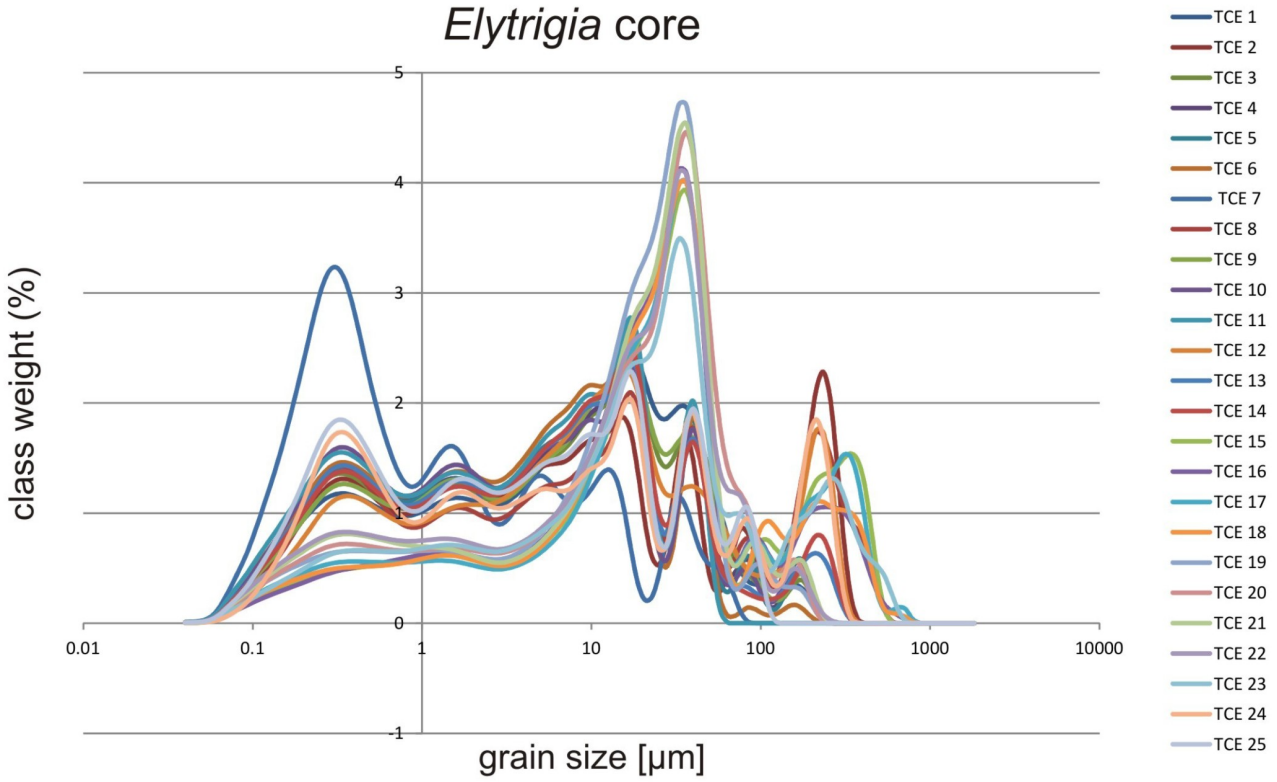

Figure G.1.: Particle size analysis (PSA) for the high marsh sediment core (TCE *Elytrigia*) from Tollesbury, showing all 25 samples. 25 samples were measured (TCE 1 to TCE 25). The x-axis represents the µm (log scale), whereas the y-axis stands for the volume % per sample.

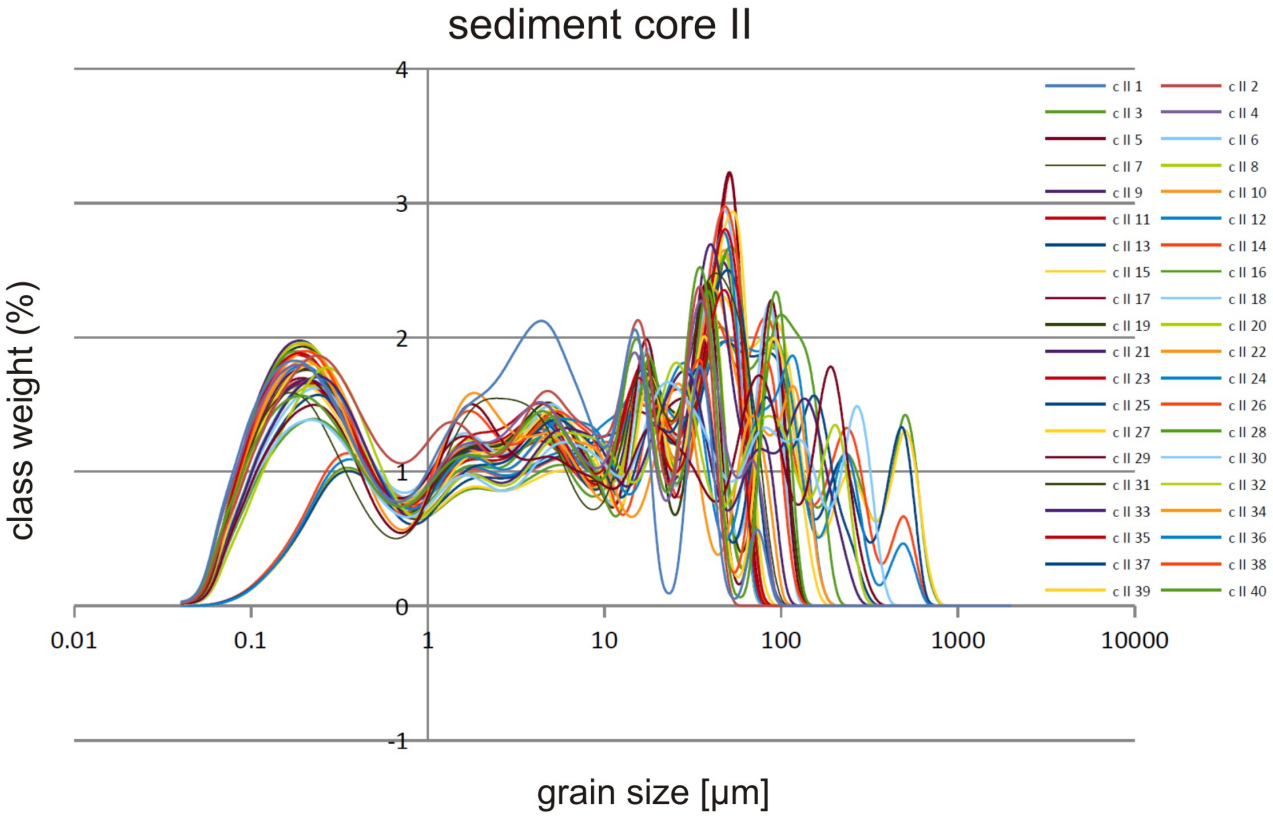

Figure G.2.: Particle size analysis (PSA) for the sediment core (c II) from Tollesbury, showing all 40 samples. 40 samples were measured (cII 1 to cII 40). The x-axis represents the µm (log scale), whereas the y-axis stands for the volume % per sample.

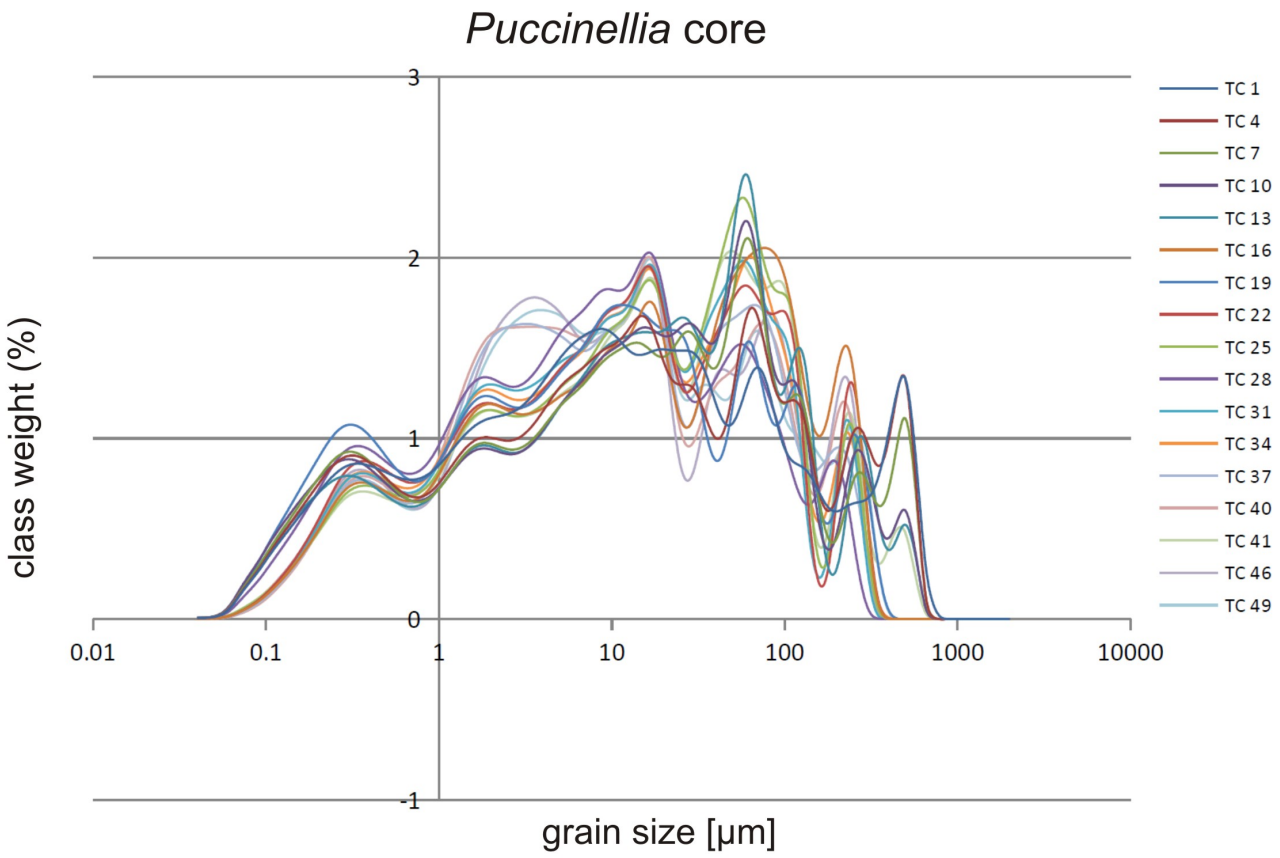

Figure G.3.: Particle size analysis (PSA) for the mid marsh sediment core (TC *Puccinellia*) from Tollesbury, showing all 17 samples (TC 1 to TC 49). The x-axis represents the µm (log scale), whereas the y-axis stands for the volume % per sample.

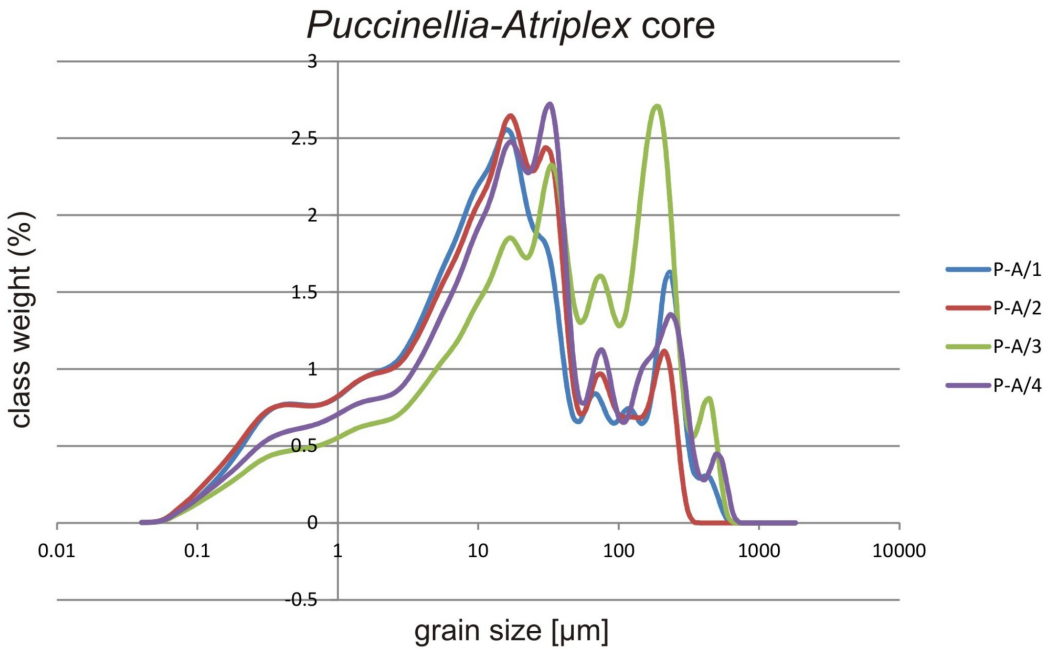

Figure G.4.: Particle size analysis (PAS) for the *Puccinellia-Atriplex* core (T 3) from Gann. 4 samples were measured (T3 1 to T3 4). The x-axis represents the µm (log scale), whereas the y-axis stands for the volume % per sample.

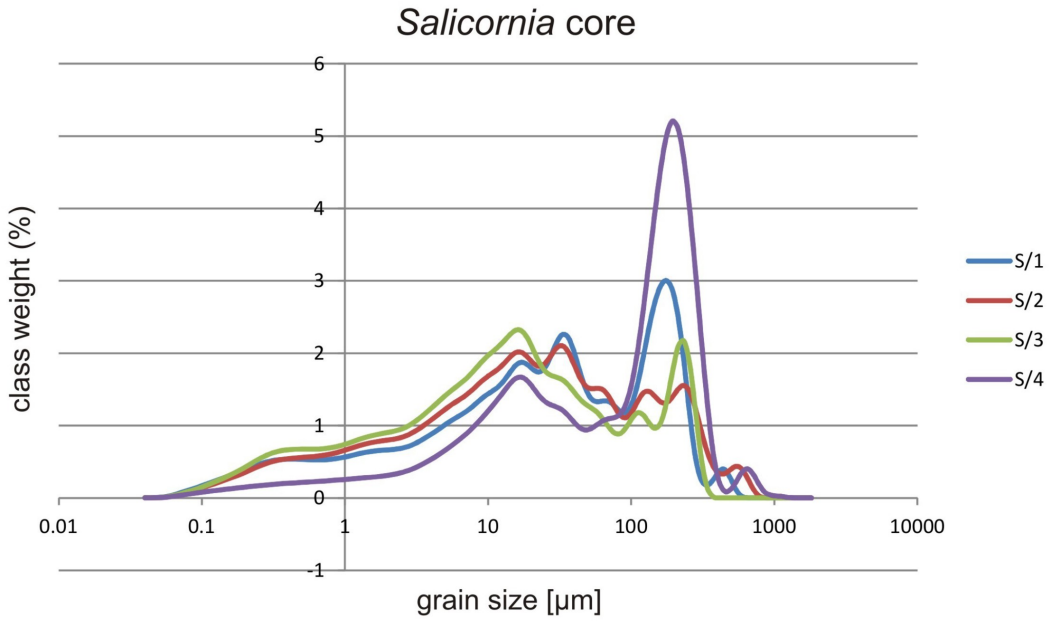

Figure G.5.: Particle size analysis for the *Salicornia* core (T 4) from Gann. 4 samples were measured (T4 1 to T4 4) The x-axis represents the µm (log scale), whereas the y-axis stands for the volume % per sample.

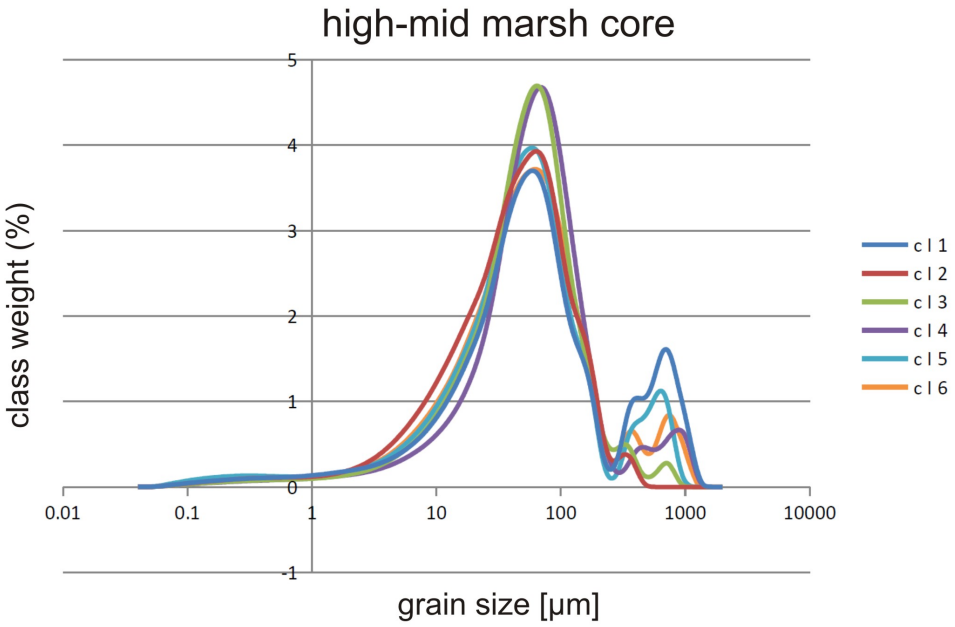

Figure G.6.: Particle size analysis (PSA) for the high-mid marsh sediment core (c I) from Loch Riddon. 6 samples were measured (cI 1 to cI 6). The x-axis represents the µm (log scale) whereas the y-axis stands for the volume % per sample.

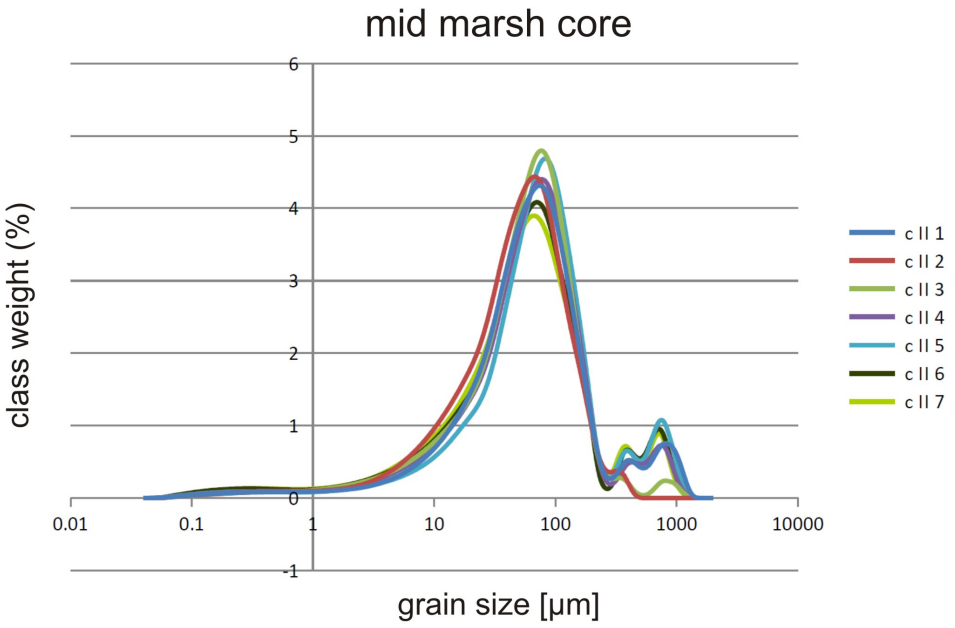

Figure G.7.: Particle size analysis (PSA) for the mid marsh sediment core (c II) from Loch Riddon. 7 samples were measured (cII 1 to cII 7). The x-axis represents the µm (log scale) whereas the y-axis stands for the volume % per sample.

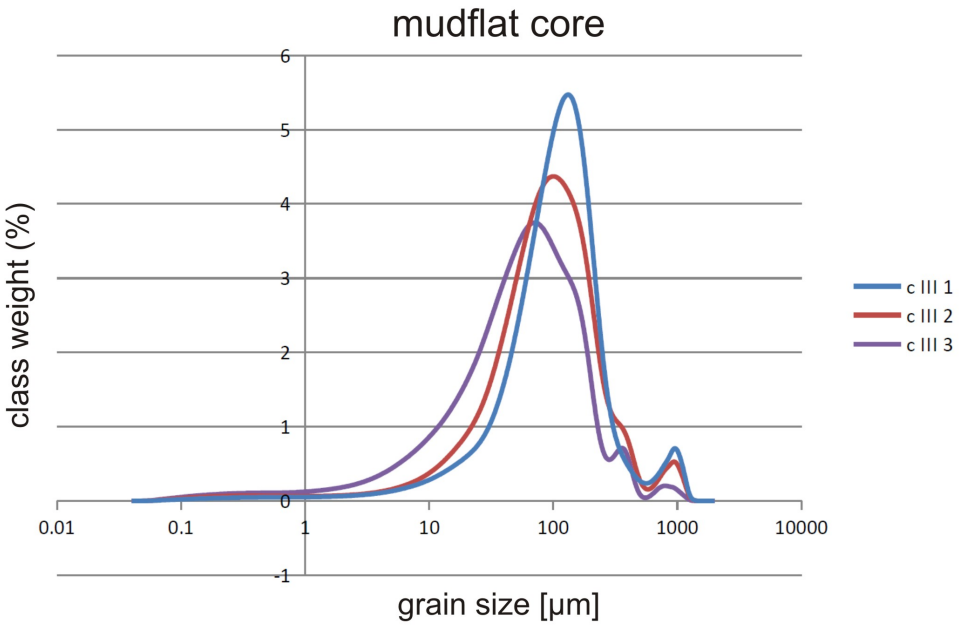

Figure G.8.: Particle size analysis (PSA) for the mudflat sediment core (c III) from Loch Riddon. 3 samples were measured (cIII 1 to cIII 3). The x-axis represents the µm (log scale) whereas the y-axis stands for the volume % per sample.

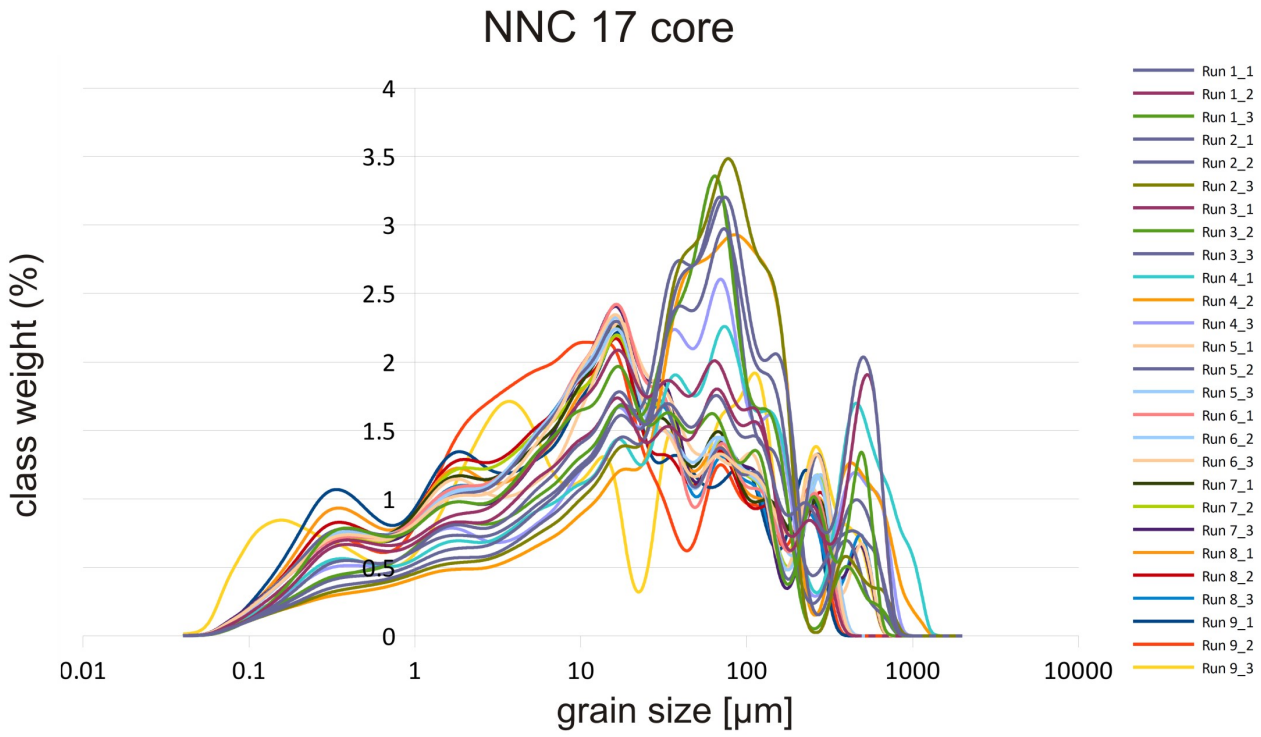

Figure G.9.: Particle size analysis (PSA) for the sediment core (NNC 17) from Holkham, showing all 18 samples (R1 1 to R 9 3). The x-axis represents the µm (log scale) whereas the y-axis stands for the volume % per sample.

Table G.1.: PSA analysis of three saltmarsh sediment cores (TCE, c II, TC) from Tollesbury. The table shows the grain size distribution in percentage values of clay, silt and sand of 57 sediment core samples.

Sample name	**clay (%)**	**silt (%)**	**sand (%)**
TCE 1	32	62	6
TCE 2	34	47	19
TCE 3	36	59	5
TCE 4	37	57	5
TCE 5	37	58	5
TCE 6	39	60	2
TCE 7	63	36	1

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Table G.1 – continued from previous page

Sample name	clay (%)	silt (%)	sand (%)
TCE 8	32	48	20
TCE 9	34	60	6
TCE 10	40	55	5
TCE 11	40	60	0
TCE 12	29	56	15
TCE 13	36	57	7
TCE 14	35	43	22
TCE 15	16	63	22
TCE 16	16	67	18
TCE 17	17	62	21
TCE 18	16	65	19
TCE 19	20	75	5
TCE 20	21	69	10
TCE 21	22	70	8
TCE 22	24	68	9
TCE 23	19	60	21
TCE 24	36	48	16
TCE 25	41	54	5
cII 1	42	24	34
cII 2	35	51	14
cII 3	36	51	13
cII 4	38	52	10
cII 5	40	50	10
cII 6	36	54	11
cII 7	32	57	11
cII 8	39	50	11
cII 9	41	49	10
cII 10	42	48	10

Continued on next page

Table G.1 – continued from previous page

Sample name	clay (%)	silt (%)	sand (%)
cII 11	38	52	10
cII 12	39	50	11
cII 13	38	50	12
cII 14	35	48	18
cII 15	34	51	16
cII 16	27	51	22
cII 17	29	44	27
cII 18	27	46	26
cII 19	28	46	27
cII 20	27	46	27
cII 21	25	48	27
cII 22	27	46	27
cII 23	24	51	25
cII 24	26	51	23
cII 25	25	52	23
cII 26	24	53	23
cII 27	24	54	22
cII 28	25	56	19
cII 29	26	55	19
cII 30	25	53	22
cII 31	28	55	16
cII 32	25	51	24
cII 33	27	50	23
cII 34	26	52	22
cII 35	24	53	23
cII 36	25	49	26
cII 37	25	51	25
cII 38	25	49	27
cII 39	24	50	26

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Table G.1 – continued from previous page

Sample name	clay (%)	silt (%)	sand (%)
cII 40	25	51	24
TC 1	18	40	43
TC 4	16	39	44
TC 7	19	41	39
TC 10	20	43	37
TC 13	19	50	31
TC 16	19	60	22
TC 19	23	42	36
TC 22	23	48	30
TC 25	25	53	23
TC 28	20	44	36
TC 31	24	56	21
TC 34	24	54	22
TC 37	24	56	20
TC 40	24	55	22
TC 43	24	56	20
TC 46	25	53	21
TC 49	25	56	19

Table G.2.: PSA analysis of two saltmarsh sediment cores (T3, T4) from Gann. The table shows the grain size distribution in percentage values of clay, silt and sand of 8 sediment core samples.

Sample name	clay (%)	silt (%)	sand (%)
T3 1	21	61	18
T3 2	22	64	14
T3 3	14	51	35
T3 4	18	62	21

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Table G.2 – continued from previous page

Sample name	clay (%)	silt (%)	sand (%)
T4 1	16	51	33
T4 2	16	56	28
T4 3	19	59	23
T4 4	7	36	57

Table G.3.: PSA analysis of all three saltmarsh sediment cores (cI, cII, cIII) from Loch Riddon. The table shows the grain size distribution in percentage values of clay, silt and sand of 16 sediment core samples.

Sample name	clay (%)	silt (%)	sand (%)
cI 1	4	49	48
cI 2	3	59	37
cI 3	3	54	44
cI 4	3	47	51
cI 5	4	54	42
cI 6	4	55	41
cII 1	3	46	52
cII 2	3	54	43
cII 3	3	47	50
cII 4	3	39	59
cII 5	2	43	55
cII 6	4	47	49
cII 7	4	49	47
cIII 1	2	22	76
cIII 2	3	38	60
cIII 3	4	48	49

Table G.4.: PSA analysis of the saltmarsh sediment core (NNC 17) from Holkham. The table shows the grain size distribution in percentage values of clay, silt and sand of 29 sediment core samples.

Sample name	**clay (%)**	**silt (%)**	**sand (%)**
R1 1	16	49	35
R1 2	18	48	34
R1 3	21	54	25
R2 1	13	50	36
R2 2	12	49	40
R2 3	11	48	41
R3 1	20	57	23
R3 2	15	55	30
R3 3	15	55	30
R4 1	16	44	40
R4 2	10	43	46
R4 3	16	49	35
R5 1	22	57	21
R5 2	22	58	20
R5 3	22	59	20
R6 1	22	59	19
R6 2	22	58	20
R6 3	23	56	22
R7 1	23	58	20
R7 2	23	58	20
R7 3	21	58	21
R8 1	25	55	19
R8 2	24	57	19
R8 3	22	58	20
R9 1	28	55	18
R9 2	23	61	17
R9 3	25	46	30

H. Age data

Appendix H, shows tables containing all data about the four different age dating methods in chapter 7.

Table H.1.: ^{137}Caesium results from the 1 m long sediment core (c IV) from Tollesbury saltmarsh. Shown are sample number with depths in centimetre [cm] and dry sediment weight in gram [g]. The ^{137}Caesium activity is then presented in Becquerel per kilo [Bq / kg] and Becquerel per gram [Bq / g], with 2 sigma in percentage [%] and error in Becquerel per kilo [Bq / kg]. From the 48 core samples, only 13 show results.

sample number	sample depth [cm]	dry sed weight [g]	Cs activity [Bq / kg]	Cs activity [Bq / g]	2 sigma [%]	Error [Bq / kg]
1	0-2 cm	70.92	34.43	0.034	5.0	1.7230
2	2-4 cm	104.78	58.51	0.059	3.3	1.9390
3	4-6 cm	108.95	82.86	0.083	3.0	2.4800
4	6-8 cm	105.75	96.03	0.096	2.9	2.8170
5	8-10 cm	112.98	94.52	0.090	2.9	2.7360
6	10-12 cm	111.56	93.85	0.094	2.9	2.7340
7	12-14 cm	110.60	53.92	0.054	3.3	1.7910
8	14-16 cm	111.43	23.30	0.023	4.8	1.1210
9	16-18 cm	114.36	15.23	0.015	6.2	0.9463
10	18-20 cm	118.08	7.295	0.007	11.2	0.8148
11	20-22 cm	120.77	4.517	0.005	16.2	0.7296
12	22-24 cm	121.01	2.633	0.003	26.1	0.6872
13	24-26 cm	122.74	1.987	0.002	33.5	0.6651

Table H.2.: ^{210}Lead results from the 1 m long sediment core (c IV) from Tollesbury saltmarsh. Shown are sample number with depths in centimetre [cm] and dry sediment weight in gram [g]. The ^{210}Lead activity is then presented in Becquerel per kilo [Bq/kg] and Becquerel per gram [Bq/g], with 2 sigma in percentage [%] and error in Becquerel per kilo [Bq/kg]. From the 48 core samples, only 9 show results.

sample number	**sample depth [cm]**	**dry sed weight [g]**	**Pb activity [Bq/kg]**	**Pb activity [Bq/g]**	**2 sigma [%]**	**Error [Bq/kg]**	**unsuported Pb [Bq/kg]**
1	0-2 cm	70.92	96.00	0.096	11.8	11.32	0.076910
2	2-4 cm	104.78	79.11	0.079	10.7	8.455	0.062285
3	4-6 cm	108.95	59.93	0.060	13.0	7.779	0.042965
4	6-8 cm	105.75	52.45	0.052	15.3	8.043	0.032000
5	8-10 cm	112.98	41.56	0.042	16.7	6.956	0.021905
6	10-12 cm	111.56	34.96	0.035	19.4	6.783	0.013935
7	12-14 cm	110.60	28.97	0.029	23.7	6.860	0.011850
8	14-16 cm	111.43	28.06	0.028	24.6	6.891	0.011590
9	16-18 cm	114.36	12.17	0.012	52.1	6.346	0.005925

Table H.3.: Sample sediment weight in gram [g] (wet and dry) as well as the calculated water content in gram [g] and percentage [%] are given for the 1 m long sediment core (c IV) from Tollesbury saltmarsh.

sample number	sample depth [cm]	sediment weight [g]	dry sediment weight [g]	water content [g]	water content [%]
1	0-2 cm	219.3	80.1	139.2	63.5
2	2-4 cm	414.5	127.8	286.7	69.2
3	4-6 cm	519.3	168.1	351.2	67.6
4	6-8 cm	683.5	208.6	474.9	69.5
5	8-10 cm	420.4	125.5	294.9	70.1
6	10-12 cm	677.9	204.4	473.5	69.8
7	12-14 cm	605.3	170.2	435.1	71.9
8	14-16 cm	589.2	166.9	422.3	71.7
9	16-18 cm	598.4	182.6	415.8	69.5
10	18-20 cm	645.4	240.7	404.7	62.7
11	20-22 cm	776.9	271.1	505.8	65.1
12	22-24 cm	692	252.4	439.6	63.5
13	24-26 cm	759.2	285.1	474.1	62.4
14	26-28 cm	731.4	310.5	420.9	57.5
15	28-30 cm	782.7	364.3	418.4	53.5
16	30-32 cm	704.6	322.9	381.7	54.2
17	32-34 cm	804.1	416.2	387.9	48.2
18	34-36 cm	742	412.4	329.6	44.4
19	36-38 cm	840.2	479.1	361.1	43
20	38-40 cm	874.6	492.9	381.7	43.6
21	40-42 cm	767.7	440.3	327.4	42.6
22	42-44 cm	903.9	528.7	375.2	41.5

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Table H.3 – continued from previous page

sample number	sample depth [cm]	sediment weight [g]	dry sediment weight [g]	water content [g]	water content [%]
23	44-46 cm	955.3	559.6	395.7	41.4
24	46-48 cm	963	583.1	379.9	39.4
25	48-50 cm	769	466.4	302.6	39.3
26	50-52 cm	875.8	540.9	334.9	38.2
27	52-54 cm	898.3	543.7	354.6	39.5
28	54-56 cm	903.6	550.9	352.7	39
29	56-58 cm	977.5	605	372.5	38.1
30	58-60 cm	807.9	506.6	301.3	37.3
31	60-62 cm	1056.5	673.1	383.4	36.3
32	62-64 cm	954.2	621.9	332.3	34.8
33	64-66 cm	917.8	612.7	305.1	33.2
34	66-68 cm	1005.2	706.1	299.1	29.8
35	68-70 cm	1288.9	933	355.9	27.6
36	70-72 cm	1062	750.9	311.1	29.3
37	72-74 cm	910.4	631.9	278.5	30.6
38	74-76 cm	1091.4	726.4	365	33.4
39	76-78 cm	985.4	642.7	342.7	34.8
40	78-80 cm	946.8	617.4	329.4	34.8
41	80-82 cm	974.8	631.9	342.9	35.2
42	82-84 cm	940.5	606.4	334.1	35.5
43	84-86 cm	891.8	575.1	316.7	35.5
44	86-88 cm	693.6	446.4	247.2	35.6
45	88-90 cm	948.5	611.1	337.4	35.6
46	90-92 cm	760.8	492.1	268.7	35.3

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Table H.3 – continued from previous page

sample number	sample depth [cm]	sediment weight [g]	dry sediment weight [g]	water content [g]	water content [%]
47	92-94 cm	872.8	564.2	308.6	35.4
48	94-96 cm	980.1	623.6	356.5	36.4

I. Dissolution experiment

Appendix I shows tables containing all data about the dissolution experiment from chapter 8.

Table I.1.: Monthly alkalinity measurements (in mEq / kg) of the Atlantis Sea Water (ASW - standard) and sediment core water (CW) without and with dead Foraminifera tests (AM, Elph, Jadam, Troch, n.d. = no data).

Sample	December 2013	January 2014	February 2014	April 2014	June 2014	July 2014	August 2014
ASW 1	2.112	1.959	2.008	2.278	2.173	2.257	2.203
ASW 2		1.59	2.153	2.225	2.248	2.127	2.128
ASW 3		1.669	2.065	2.231	2.227	2.236	
ASW Am 1		1.506	1.973	2.32	2.186		
ASW Am 2		1.609	2.176	2.378	2.311		
ASW Am 3		1.074	2.115	2.054	2.267		
CW 1	2.646	1.489	n.d.	2.902	2.697	2.845	2.742
CW 2		1.404	2.771	2.799	2.751	2.696	2.649
CW 3		2.19	2.527	2.865	2.707		
CW Am 1		2.48	2.735	2.924	2.816	2.472	
CW Am 2		1.828	2.816	2.725	2.825	2.610	
CW Am 3		2.615	2.719	2.678	2.762		
CW Elph 1		2.591	2.795	2.983	2.91	2.501	
CW Elph 2		2.387	2.702	2.528	2.812		
CW Elph 3		2.188	2.826	2.995	2.857		
CW Jadm 1		1.949	2.882	2.854	2.744		

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Table I.1 – continued from previous page

Sample	December 2013	January 2014	February 2014	April 2014	June 2014	July 2014	August 2014
CW Jadm 2		2.225	2.844	2.592	2.941		
CW Jadm 3		2.438	2.666	2.76	2.876		
CW Troch 1		2.255	2.657	2.954	2.809	1.506	
CW Troch 2		2.054	2.933	2.868	2.812		
CW Troch 3		2.009	3.648	2.919	2.907		

Table I.2.: Monthly pH measurements of the Atlantis Sea Water (ASW - standard) and sediment core water (CW) without and with dead Foraminifera tests (AM, Elph, Jadam, Troch, n.d. = no data).

Sample	December 2013	January 2014	February 2014	April 2014	June 2014	July 2014	August 2014
ASW 1	7.87	7.17	7.62	7.47	7.58	7.61	7.53
ASW 2		7.35	7.51	7.53	7.64	7.75	7.78
ASW 3		7.35	7.39	7.63	7.7	7.56	
ASW Am 1		n.d.	7.44	7.46	7.41		
ASW Am 2		7.19	7.36	7.49	7.53		
ASW Am 3		6.39	7.45	7.64	7.47		
CW 1	7.54	6.87	n.d.	7.67	7.7	7.64	7.93
CW 2		6.93	7.62	7.74	7.85	7.71	7.8
CW 3		7.23	7.68	7.78	7.8		
CW Am 1		7.34	7.68	7.57	7.43	7.58	
CW Am 2		7.19	7.76	7.67	7.5	7.54	
CW Am 3		7.41	7.58	7.66	7.56		

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Table I.2 – continued from previous page

Sample	December 2013	January 2014	February 2014	April 2014	June 2014	July 2014	August 2014
CW Elph 1		7.33	7.47	7.56	7.47	7.53	
CW Elph 2		7.38	7.73	7.65	7.47		
CW Elph 3		7.36	7.72	7.65	7.63		
CW Jadm 1		7.53	7.74	7.44	7.56		
CW Jadm 2		7.47	7.77	7.62	7.51		
CW Jadm 3		7.45	7.65	7.68	7.63		
CW Troch 1		7.4	7.45	7.59	7.54	7.13	
CW Troch 2		7.31	7.76	7.63	7.74		
CW Troch 3		7.26	7.89	7.46	7.57		